G.E.C. Journal

VOL. IV. NOVEMBER, 1933. No. 4.

CONTENTS

PAGE

FRONTISPIECE: THE DIESEL-ELECTRIC TUG "ACKLAM CROSS" - - - - - - - - - - 198

THE ELECTRICAL CHARACTERISTICS OF THE NEW "OSIRA" LAMP - - - - - - - - - - 199
By J. W. Ryde.

THE "CHANCE" SAND FLOTATION SYSTEM OF CLEANING COAL 208
By H. L. Wood.

FLOODLIGHTING—PART II - - - - - - - - 215
By Thomas E. Ritchie.

A NEW CONSTRUCTION FOR RECEIVING VALVES - - 229
(Manufactured under the trade mark "Catkin")
By C. J. Smithells and D. A. Rankin.

THE USE OF THE MOTION CAMERA FOR TESTING ELECTRICAL APPARATUS - - - - - - - - - - 236
By W. Wilson.

ELECTRICAL EQUIPMENT FOR THE BRITISH GRID.
PART I—OUTDOOR SUB-STATION EQUIPMENT - - 241
By A. M. Anderson.

Published quarterly by

THE GENERAL ELECTRIC Co., LTD.
Magnet House, Kingsway, London.

COPYRIGHT.

PRICE 1/-

Copies can be obtained from the above address.

DIESEL-ELECTRIC TUG *ACKLAM CROSS*

The first Diesel-electric tug to be built in Great Britain and the first to be fitted with electrical starting equipment. A full description of the complete G.E.C. electric propulsion equipment installed will be given in the next issue of the *G.E.C. Journal*.

G.E.C. Journal

VOL. IV. NOVEMBER, 1933. No. 4.

The Electrical Characteristics of the New "Osira" Lamp.

By J. W. RYDE.
Research Laboratories of The General Electric Co., Ltd., Wembley, England.

The new "Osira" discharge lamp was developed in the G.E.C. Research Laboratories at Wembley, and the experimental street-lighting installation in East Lane, which was put into operation on 22nd June, 1932, was the first installation in the world to employ these lamps. Following on this successful trial, a larger installation on a mile of the Watford Road, Wembley, Middlesex, was opened on March 2nd, 1933. Since then, several other installations have been completed, among which may be mentioned those at Croydon, Stockport, Kingsbury, Manchester and Bridlington. Many more are in various stages of completion in different parts of the Country.

THE new "Osira" lamp, figs. 1 and 2, consists of two cylindrical bulbs, one within the other; the inner bulb contains rare gases at low pressure and a little mercury, while the space between the two bulbs is evacuated.

The electric discharge takes place in the inner bulb between electrodes sealed in at each end. These electrodes consist of small sticks of alkaline earth oxides, held in spirals of tungsten wire. In order to activate the oxides, they are heated to a high temperature during manufacture. This is done by passing a current through the spirals and, for this purpose, two leads are sealed through the glass at each end. Once the oxides have been activated, the double leads are no longer needed and each pair is therefore connected together. A single lead from each end is then carried up through the glass pinch to a standard Goliath Edison Screw cap.

The spiral wire twisted round the inner bulb is connected to the lower electrode only; its purpose is to increase the potential gradient in the neighbourhood of the upper electrode at the moment of starting. This assists the initiation of the discharge when the lamp is first switched on.

When the voltage is applied, the discharge takes place in the rare gases throughout the volume of the inner bulb. As this bulb warms up, the mercury is volatilised and the pressure rises. The discharge then begins to contract and finally takes the form of a narrow column, about 6 inches long, extending between the two electrodes. A brilliant light is emitted by the electrically excited atoms in this thin column, which thus forms the counterpart of the filament of a tungsten lamp.

The new lamp lights up automatically when switched on; no gear is needed for starting the discharge, nor are any filament transformers required to heat the electrodes. It is connected directly to the A.C. supply in series with a choke. A condenser, to correct the power factor, may be placed across the supply if desired; its absence does not, however, affect the performance of the lamp itself.

The lamp takes 400 watts and has a luminous efficiency of well over twice that of a gasfilled tungsten filament lamp of corresponding wattage. The average life is about 1,500 hours.

The colour rendering, although not perfect, is reasonably good; blues, greens and yellows appear as brilliant as in daylight but, at the present stage of development, red colours appear brownish. The spectrum consists of lines in the yellow, green,

blue-green and blue, together with many fainter ones in the yellow and orange ; in addition, a certain amount of continuous spectrum extends from the blue to the orange regions.

Before discussing the somewhat complicated electrical characteristics of these "Osira" lamps it will be interesting to consider, for comparison, some simpler and more familiar cases.

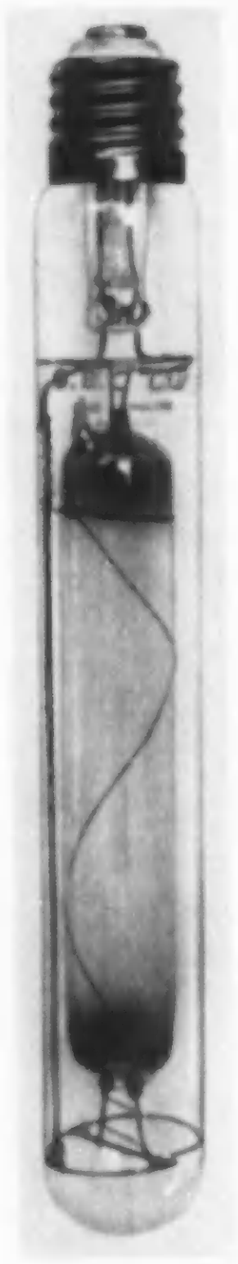


Fig. 1.—The new "Osira" electric discharge lamp.

Fig. 2.—Diagram of the new lamp showing the internal construction.

CHARACTERISTICS OF TUNGSTEN FILAMENT LAMPS.

When a potential is applied to a constant resistance, it is known by Ohm's law, that the current which will flow is determined by the ratio of the applied voltage to the resistance in the circuit. The electrical characteristics are then simply described by statement of the value of this resistance. It may, however, happen that the resistance in some part of the circuit does not remain constant. For example, in the familiar case of a tungsten lamp the resistance of the filament increases with its temperature. The resistance of a tungsten filament is, in fact, about 12 times as great at the normal burning temperature as it is when cold. The current, when first switched on, will therefore be much greater than normal during the short period which elapses before the filament attains its final high temperature. This effect becomes very noticeable in the case of the thick filaments used in very large lamps because such thick wire takes a comparatively long time to heat up.

If the current voltage characteristics of such a filament be determined, always allowing plenty of time for the temperature to become constant after each change of voltage is made, a curve is obtained such as is shown by the thick line in fig. 3. The dotted line gives the value of the current which would flow if the filament resistance remained constant instead of increasing with temperature.

Assuming that the lamp is burning on a certain voltage and that its resistance has steadied up to a constant value, Ohm's law can be applied to find what will be the current which will flow immediately after a change of voltage takes place. It will be, in fact, the ratio of the new voltage to the resistance just before the change. The current will not of course remain at this value but will immediately begin to approach some new steady value as the temperature, and therefore the resistance, of the filament alters. The time taken to attain the new value will depend upon the thermal capacity of the filament and various other factors.

If it is wished to describe the electrical characteristics of the lamp it would be necessary to give first a curve such as fig. 4, showing how the current falls from its initial value when the lamp is first switched on, and secondly the steady value characteristic, fig. 3. The current which would flow immediately after a change in voltage can then, as has been shown, be found by Ohm's law and the final steady value is given by fig. 3.

Considering a particular case in which the potential across the lamp is 74 volts, corresponding to point A in fig. 3, if the voltage is increased very slowly to 94, for example, the current-voltage characteristic will correspond to the curve between A and B. If, however, the increase of voltage were very sudden, the instantaneous characteristic would be the part AC of a line passing through the origin. The current would thus rise to 130 immediately after the change and then fall gradually to 118, corresponding to the point B, as the filament increased in temperature.

With this in mind, the case of the new lamp can now be considered.

CHARACTERISTICS OF THE NEW "OSIRA" LAMP.

In an electrical discharge lamp the current is carried by ions and, roughly speaking, the effective resistance depends on the number of these present

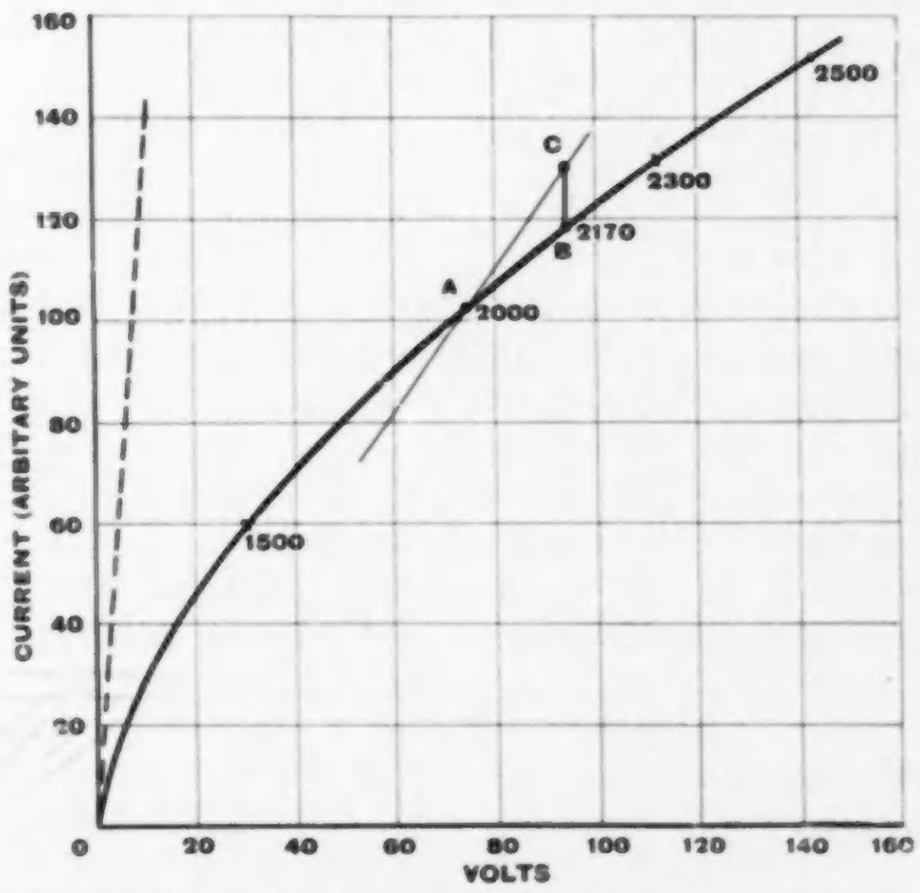


Fig. 3.—Current-voltage characteristic for a tungsten lamp. The figures along the curve are the filament temperatures.

in the lamp. Now these ions, which are negatively charged electrons and positively charged atoms, are formed by the discharge itself at a rate which increases with the current. They recombine extremely rapidly, however, and form normal atoms once more. The number present, and thus the resistance of the tube, depends at any given moment on the actual current passing at that moment. The lamp resistance therefore does not remain constant even momentarily when the voltage is changed. For this reason Ohm's law cannot be applied and a knowledge of the effective resistance of a discharge lamp at any instant tells us very little. The effect is somewhat as though the filament in the incandescent lamp case had no thermal capacity and so changed its temperature, and therefore its resistance, instantaneously when the voltage was varied.

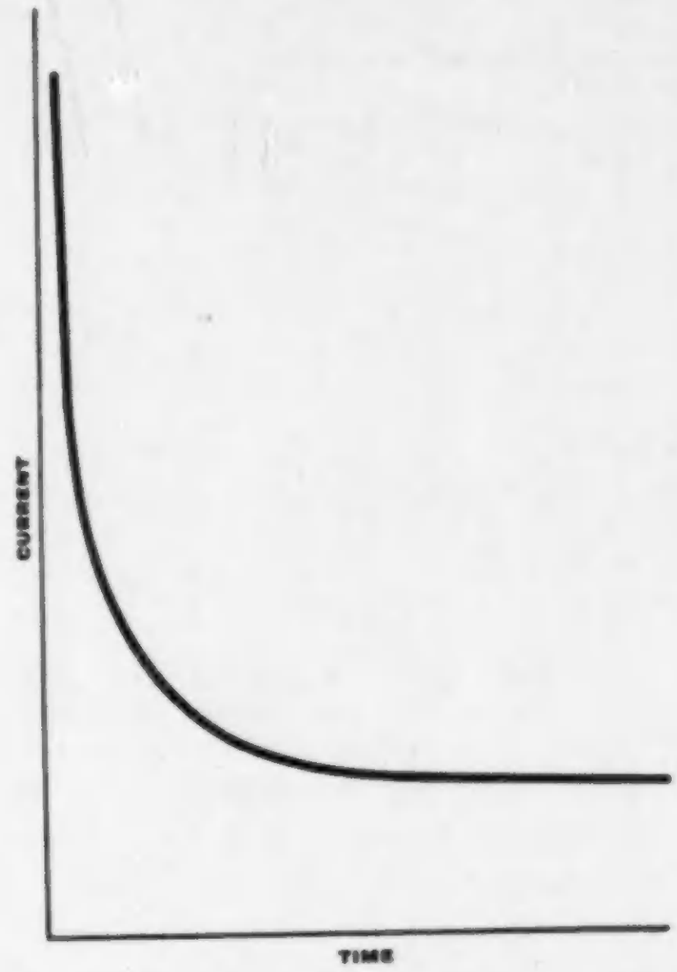


Fig. 4.—Current-time curve for a tungsten filament lamp.

In the case of the new "Osira" lamp there is, however, an effect analagous to the gradual change of resistance of a filament lamp with temperature. This results from the fact that, for a given current, the potential across the discharge lamp depends upon the number of gas and vapour atoms present per unit volume. Now as long as there is any liquid mercury available, an increase in the temperature of the inner bulb will vaporise more mercury and thus change the electrical characteristics. Owing to the large thermal capacity of the discharge lamp bulb, the time taken to reach steady values will be much greater than in the case of the filament lamp.

The fact that these two effects are both present makes it impossible to deduce the instantaneous characteristic from the steady curves, except at the higher wattages at which all the mercury remains vaporised even after a decrease in voltage has taken place.

When describing the electrical characteristics of the discharge lamps three sets have to be considered, namely, starting characteristics, steady characteristics and instantaneous characteristics. The starting characteristics are those showing the variation with

time after switching on; the steady characteristics assume that the temperature has steadied up to its final value after any change has been made, and the instantaneous characteristics refer to the momentary

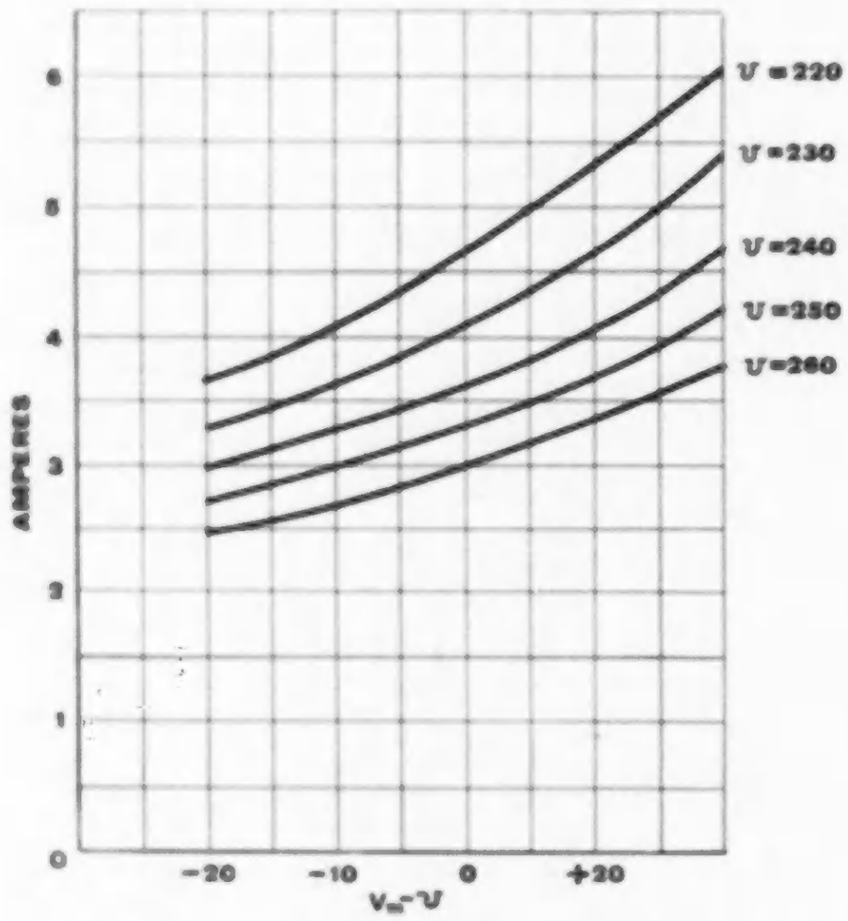


Fig. 5.—Values of the mains starting currents (condenser capacity, 20 microfarads).

values which occur immediately after a change in one or other of the variables has taken place.

It has been shown that the ions which carry the current are produced by the discharge itself and also

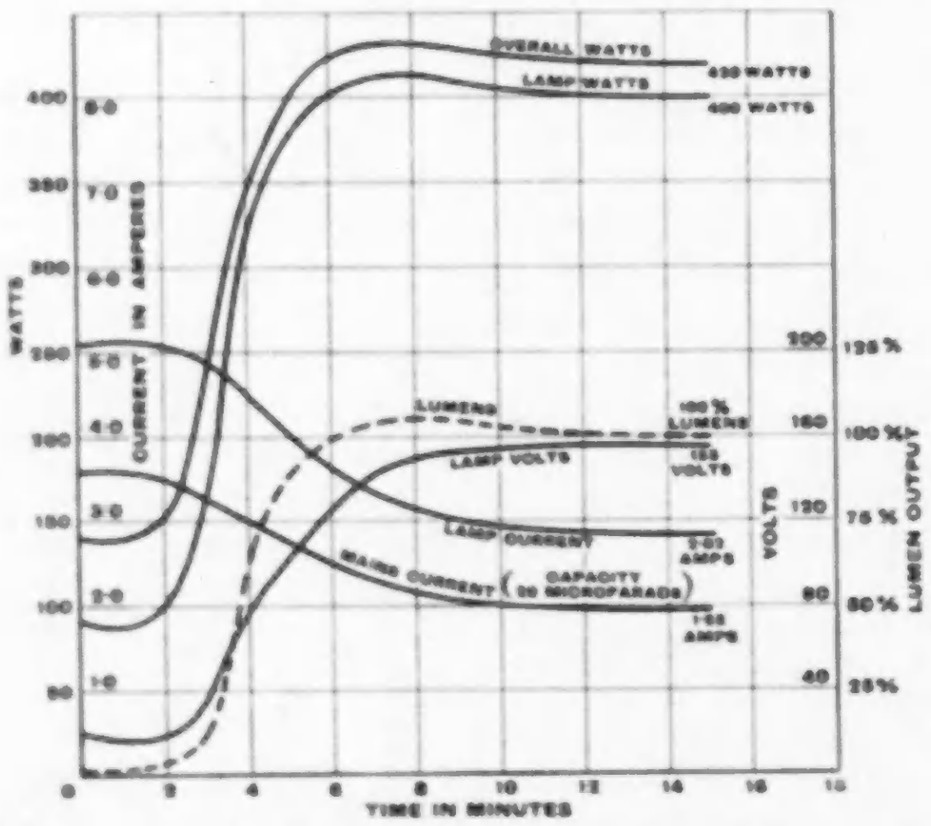


Fig. 6.—Starting characteristics for the 400 watt "Osira" lamp run in series with the special G.E.C. choke. Supply voltage 240 A.C.; Condenser across supply mains, 20 microfarads.

that the effective resistance of the lamp decreases as the number of ions present increases. If, therefore, the lamp is connected to a constant potential supply, sufficient to start the discharge, the current which first passes will produce more ions and these in turn will produce a larger current. Theoretically, there is nothing to prevent the current rising to enormous values in this way and, in practice, it will continue so to rise until the lamp fails catastrophically. For this reason it is necessary to include an impedance in the circuit; this will drop the voltage across the lamp when the current rises and thus stabilise the discharge. A resistance will do for this purpose but, on alternating current, a choke is preferable because the wattage loss in it is much smaller. A specially designed choke, having a very low power loss, has been produced by the G.E.C. for this purpose. In its original form, the air gap was variable so that the choke could be adjusted for use on different supply voltages. In the latest type this is more conveniently achieved by means of tappings.

The inclusion of a choke means that the power factor will be somewhat low, unless a condenser is placed across the mains to correct it. It will be seen therefore, that not only must we investigate the electrical characteristics of the lamp alone but also the overall characteristics at the mains.

The three sets of characteristics both at the lamp itself and from the mains side will now be described. The curves and figures will, in all cases, be representative average values, and it will be assumed that the supply is alternating current having a frequency of 50 cycles. Also, in the case of the overall characteristics, it is to be understood that the special G.E.C. choke is employed together with a 20 microfarad condenser.

STARTING CHARACTERISTICS OF THE "OSIRA" LAMP.

At ordinary outdoor temperatures the mercury is practically all condensed, so that some permanent gas must be included in the bulb in order that the discharge may start. One or more of the rare gases is used for this purpose since these do not appreciably disappear under the action of the discharge, nor do they attack the electrodes. Moreover, the potential necessary to start the discharge is lower in the rare than in the more common gases. In the case of the "Osira" lamp it has been possible to obtain a starting potential so low that all lamps will light with certainty on supplies of 230 volts and over. No auxiliary starting device is therefore necessary.

At the moment of switching on, the discharge takes place through the rare gas which, for example, may be argon at a pressure of a few millimetres. Under these conditions very little light is emitted and the potential across the lamp itself is only about 20 volts. The current passing through the lamp is then almost entirely dependent upon the impedance of the choke and its value is practically the same as if the lamp were short-circuited. When designing

the choke we can therefore make this starting current have more or less what value we like. There are, however, various points to be considered in this connection. If we choose too high a value, the mains starting current, although reduced because of the condenser, will still be relatively high and this will mean that there will be a large voltage drop in the cables of the installation at the moment of starting. If this potential drop is too great it may be found that a few of the lamps will fail to start because the potential across them is less than the necessary 230 volts. On the other hand very little light is emitted until the mercury is vaporised and the time taken for this to occur depends on the lamp starting current. It follows that if we make this current too low, some time will be taken before the lamp gives its full light output. In designing the special choke a suitable compromise has therefore been made.

A series of curves is given in fig. 5 connecting the mains starting current, in amperes, with the supply voltage V_m and the voltage v for which the choke has been set. The abscissae represent the differences between V_m and v, and a curve is given for each value of v. Thus, if V_m and v are both 240 volts the curves show that the mains starting current is 3.6 amperes. If, however, the supply voltage were 230, while the choke still remained set for 240, we should have $V_m - v = -10$ and the starting current, read from the curve for $v = 240$, would be 3.2 amperes.

If the condenser were removed, the mains current would then be the same as that flowing through the lamp. This value may be obtained with sufficient accuracy for most purposes, by adding 1.5 amperes to the mains current read from the curves. Thus, the starting current in the lamp, when both V_m and v are 240, is given by $3.6 + 1.5 = 5.1$ amperes. Actually, the true average value is 5.05. Again, if the choke were set for 230 volts and the mains voltage were 250, then the mains starting current would be 5.4 amperes and it follows that the lamp starting current would be 6.9 amperes.

The potential required to start the lamp varies with different lamps and to some extent with the lamp temperature at the moment of switching on. If, in the case of the standard 230 to 250 volt lamps, the supply is below 230 volts, then a certain proportion of the lamps in an installation may fail to start. This proportion will be larger the lower the mains voltage. Once the lamps are burning, however, the applied potential may be reduced considerably, provided that this is done slowly. This point will be referred to later when discussing the instantaneous characteristic.

If the supply is switched off and then on again, the lamp will be extinguished and will not restart immediately, because the starting potential is greater when the pressure of mercury vapour is high. The lamp will, of course, start again automatically a few minutes later when its temperature has fallen

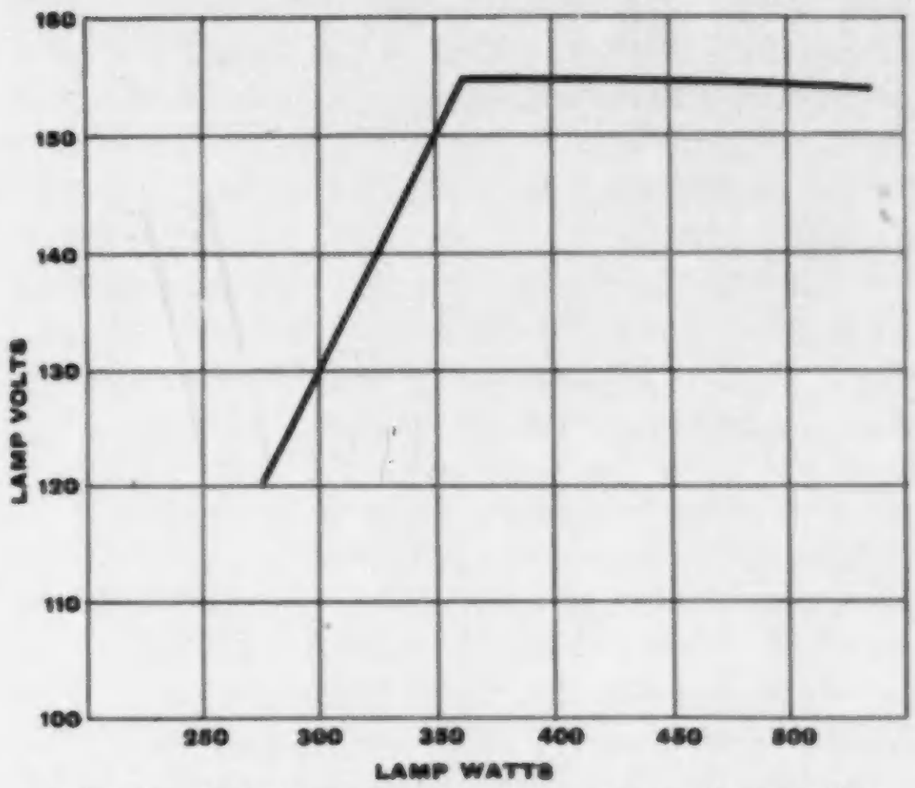


Fig. 7.—Relation between the watts and potential across an average "Osira" lamp.

and some of the vapour has condensed, thus reducing the starting potential.

Here it is convenient to discuss how the variables change with time just after the lamp has been switched on.

A complete set of starting characteristics is shown in fig. 6 for an "Osira" lamp running on

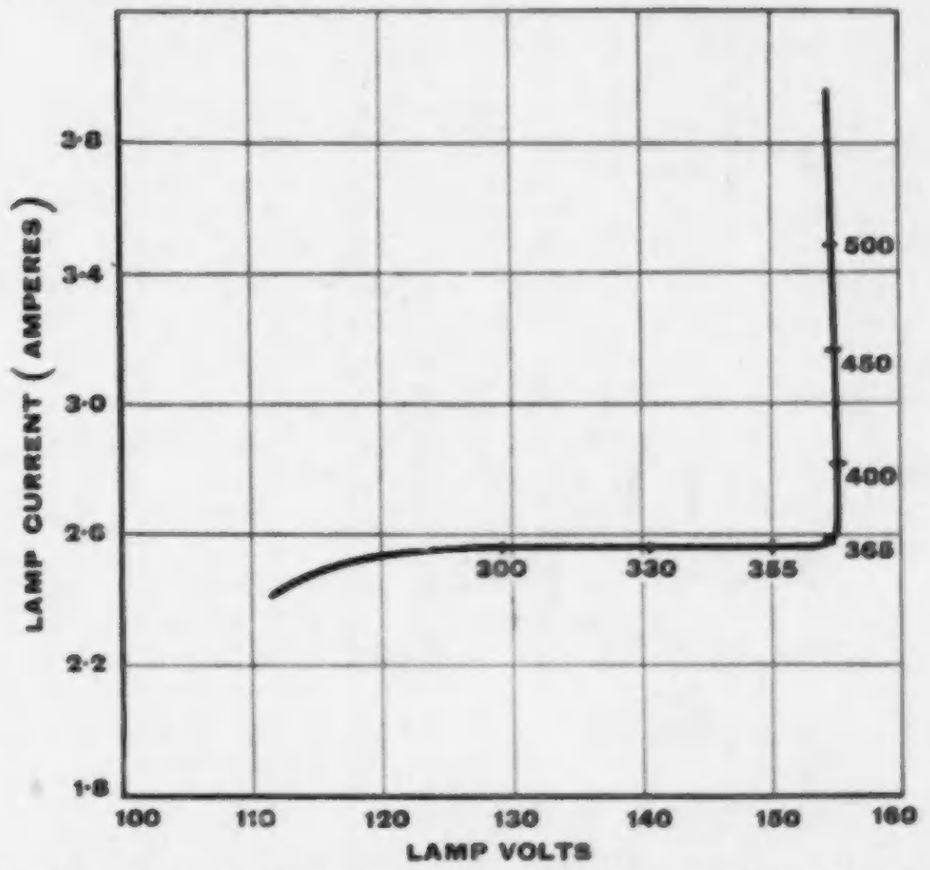


Fig. 8.—Relation between the current and voltage for an average "Osira" lamp (steady characteristics, A.C. 50 cycles). The figures along the curve refer to the lamp watts at each point.

240 volts A.C. As the lamp warms up, the mercury is gradually vaporised and the number of atoms per unit volume in the discharge path increases many hundred times. As a result, the potential across the lamp increases, as shown in the illustration,

from the initial value of 19 volts to the final steady value of about 155 volts and at the same time the lamp current drops to 2.85 amperes and the mains current to 1.95 amperes. The lamp wattage, which at starting is about 100, increases as the lamp temperature rises and then passes through a small maximum, finally taking up the steady, standard value of 400 watts.

As regards the light output, it is found that, for a given form of lamp, there is a direct relation between the lumens emitted and the lamp wattage. After about 220 watts or 60 volts has been reached, this relation is a linear one, so that the lumen output curve, shown as a dotted line in the figure, is of much the same form as that of the lamp wattage.

The overall mains wattage curve, when both choke and condenser are in circuit, is very similar in form to that shown for the lamp wattage. At the moment of starting the overall value is, however, 141 watts and the final value 420 watts.

The total power loss in the special choke and condenser is thus only 20 watts during steady running conditions. It is, however, somewhat more during the first few minutes after starting, since the current is then higher. In fig. 6 the mains current curve is also shown for the case where a 20 microfarad condenser is connected across the supply. It will be seen that, at starting, the mains current

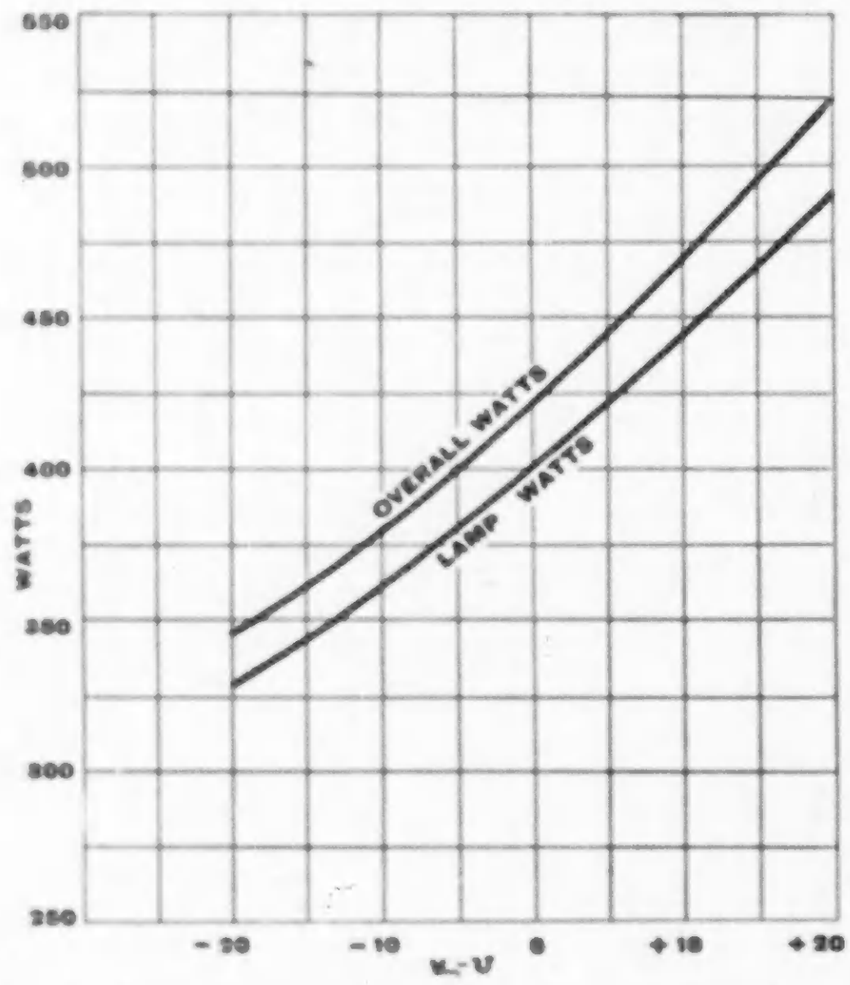


Fig. 9.—Curves connecting the lamp and overall watts with the difference between supply volts V_m and the v for which the choke is set.

is about 3.6 amperes, while the steady running value is only 1.95 amperes.

STEADY CHARACTERISTICS.

We will now consider the steady characteristics. A typical curve connecting the lamp volts with watts is shown in fig. 7. It will be seen that as the wattage increases, the voltage across the lamp increases for some time and then remains more or less constant. This is accounted for by the fact that, as the wattage

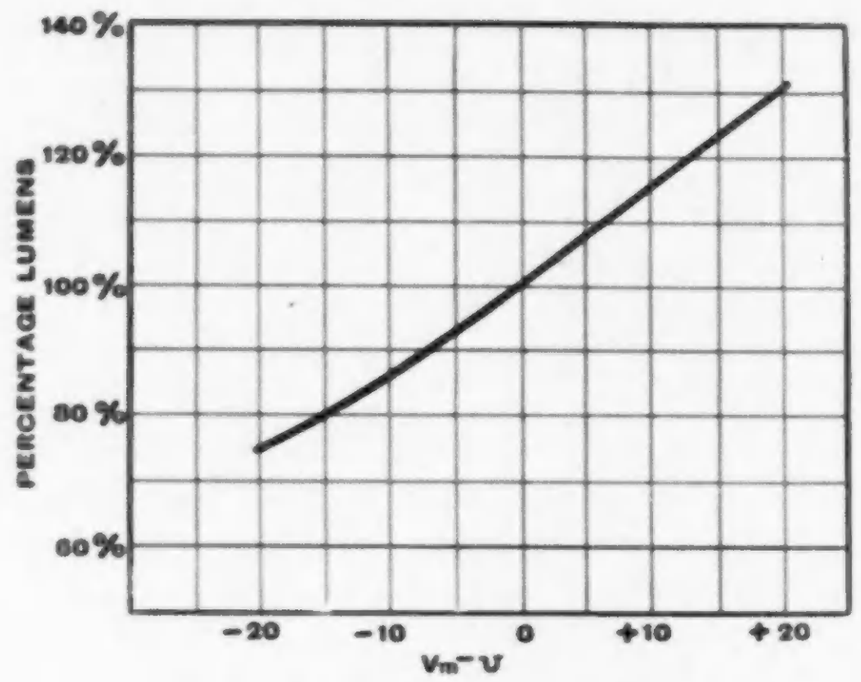


Fig. 10.—Relation between the light output in lumens of an "Osira" lamp and the difference $V_m - v$.

increases, the temperature of the inner bulb also increases and consequently more and more mercury is volatilised. The higher the vapour pressure in the tube the higher will be the potential across the lamp, so that at first the voltage also rises steadily. A time comes, however, when no mercury remains to be volatilised and, when this point is reached, the lamp voltage becomes practically constant. If the current through the tube is still further increased, the potential will drop slightly on account of the fact, common to most electrical discharges, that the voltage decreases as the current increases.

A typical curve is given in fig. 8 connecting the lamp current and the potential across the lamp terminals. Values of the lamp wattage are marked at various points along the curve. It will be seen that as soon as the mercury is all vaporised, which occurs at about 375 watts, the voltage remains at a steady value while the current increases. At the higher wattages the small fall in the voltage, which we have previously mentioned, again occurs.

The last two characteristics discussed pertain solely to the lamp itself and are therefore practically independent of the choke. Characteristic curves for various lamps may differ to a small extent in the position of the knee and also in the value of the voltage corresponding to the horizontal portion of fig. 7.

In figs. 9 and 10 is shown the way in which the watts and lumens vary when, the choke having been set for some definite voltage v, the supply voltage V_m changes. If the mains voltage is equal to that for which the choke has been set, $V_m - v = 0$ and it may be seen from the curves that the lamp

wattage will be 400, the overall watts, including losses in the choke and condenser, will be 420 and the light output 100 per cent. If now the supply increases by 10 volts, and the choke remains unaltered, the curves show that the lamp watts will

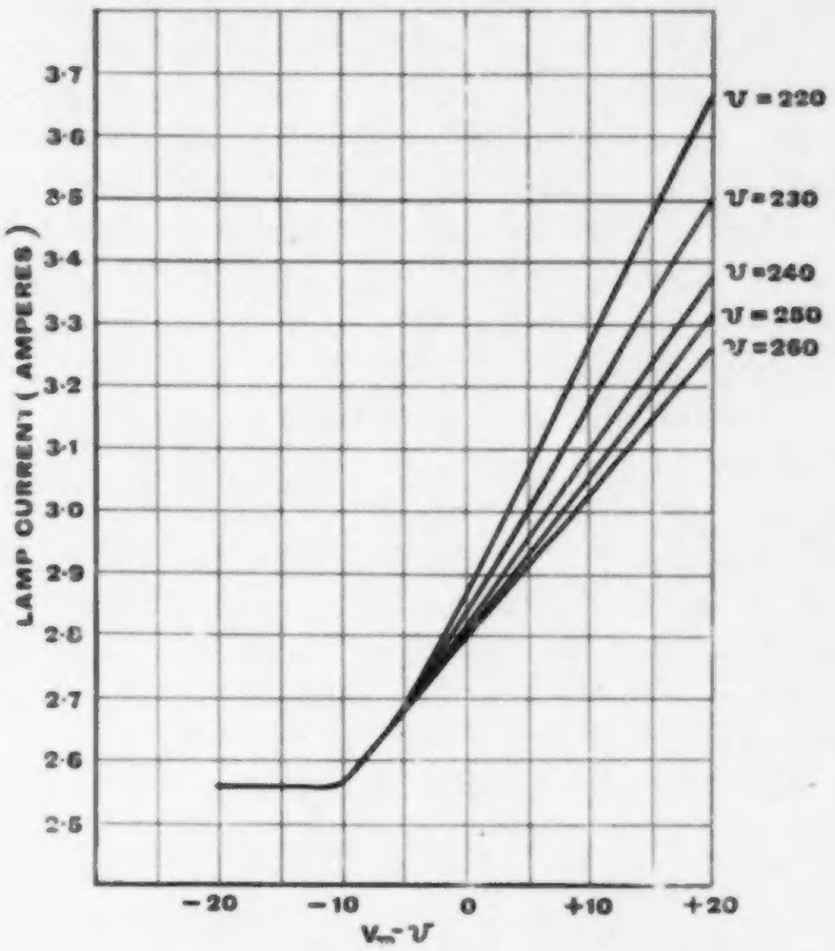


Fig. 11.—Lamp currents for various values of V_m and v (steady characteristics).

rise to 445 and the lumens will increase by about 15 per cent.

As a rough rule it can be said that a change of 1 per cent in supply volts corresponds to a 2.6 per cent change in watts and a 3.5 per cent change in lumens.

These figures may be compared with those for the corresponding gasfilled tungsten lamp for which a 1 per cent change in volts corresponds to a 1.6 per cent change in watts and a 3.9 per cent change in lumen output. The variation of light output, due to changes in the supply voltage, is thus rather less in the case of "Osira" lamps. It is also seen that if the supply voltage increases or decreases, the efficiency, just as in the case of tungsten lamps, will likewise increase or decrease, but to a somewhat smaller extent.

Small variations necessarily occur between different lamps and, if the choke were not designed to compensate for this, the watts taken by various lamps might differ appreciably. When the special G.E.C. choke is used, the wattage curves for all the lamps will follow closely that given in fig. 9, over the voltage range of 230 to 260 volts. Also the differences between the curves, corresponding to various values of v, are so small that a single curve suffices for all cases.

The lamp and mains steady current characteristics are shown in figs. 11 and 12. Here it is necessary to give separate curves for different values of v, as in the case of the mains starting current curves discussed previously and shown in fig. 5. If no condenser were used, the mains current would, of course, be the same as the lamp current, values of which are given in fig. 11. Small changes in the shape and position of the curves may be found with different lamps, but such changes will not be important.

Before leaving the subject of the steady running characteristics, the important question of the power factor must be considered.

POWER FACTOR.

There are three principal power factors to be considered. That of the lamp itself, that of the lamp together with the choke and finally the overall power factor of the lamp, choke and condenser.

In ordinary electrical engineering it is usual to equate the power factor to cos ϕ where ϕ is the angle of lag of the current behind the impressed voltage. This is, however, only true of strictly sinusoidal wave forms. The occurrence of a power factor less than unity, when the wave form differs from a sine curve, does not at all necessarily mean that the current is lagging or leading. It may be largely, or even entirely, due to the wave form.

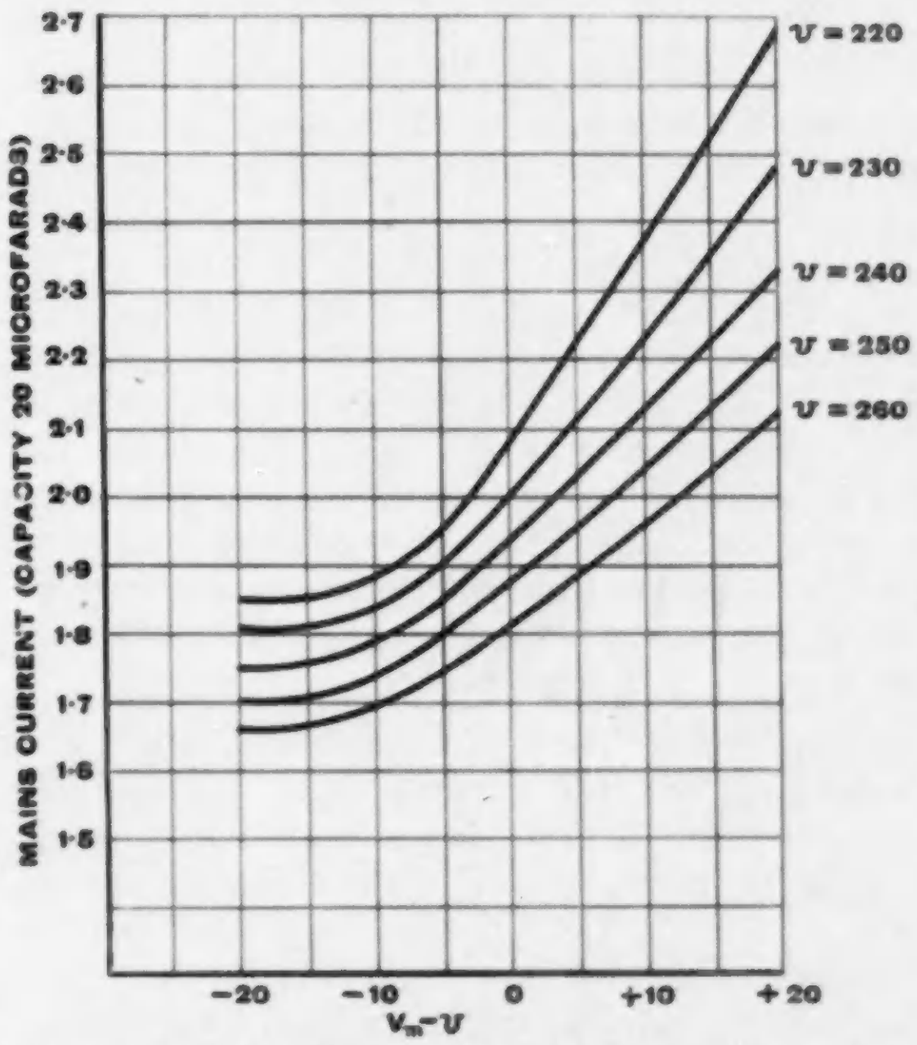


Fig. 12.—Relation between the mains currents and the difference $V_m - v$ (steady characteristics).

In this case it is not possible to illustrate the state of affairs by means of the usual vector diagrams.

In the case of the new lamp the current and voltage across it are very nearly in phase but the power factor is about 0.92, owing to deviations of

the wave form from the purely sinusoidal type. On the mains side, however, the presence of the choke makes the current lag considerably behind the voltage and thus reduces the power factor. With no condenser in circuit this power factor is about 0.12 at starting, but it quickly rises to the steady value of 0.62. This latter can generally be corrected up to a value somewhat above 0.9 by the use of condensers. In "Osira" street lighting installations, a condenser of 20 microfarads is usually employed and this raises the overall power factor to the very satisfactory value of about 0.90.

The data so far considered are summarised, for convenience, in the following tables, for the cases when the supply is 230 and 240 volts A.C. 50 cycles and the choke has been set for these same voltages.

TABLE I.

230 VOLT SUPPLY.

	Starting Values.	Steady Running Values.
Lamp Current (amperes) ..	5.6	2.82
.. Volts	19.0	155
.. Watts	99	400
.. Power Factor	0.93	0.92
Mains Current (amperes) ..	4.1	1.99
.. Volts	230	230
.. Watts	145	420
.. Power Factor (no condenser)	0.11	0.65
.. Power Factor (20 microfarad condenser) ..	0.15	0.91

TABLE II.

240 VOLT SUPPLY.

	Starting Values.	Steady Running Values.
Lamp Current (amperes) ..	5.05	2.82
.. Volts	19.0	155.0
.. Watts	91.0	400.0
.. Power Factor	0.94	0.92
Mains Current (amperes) ..	3.6	1.95
.. Volts	240	240
.. Watts	141	420
.. Power Factor (no condenser)	0.12	0.62
.. Power Factor (20 microfarad condenser) ..	0.16	0.90

INSTANTANEOUS CHARACTERISTICS.

The instantaneous characteristics, besides being of considerable interest in themselves, are also of importance practically, since they illustrate what happens when sudden changes occur in the supply voltage or in the circuit. First of all the current-voltage characteristic of the lamp itself will be discussed; this will be a function of the lamp alone and will be independent of the choke employed.

Both the instantaneous and the steady characteristics of an average lamp are shown in fig. 13. The steady characteristic is formed by the lines AD and DF; it is the same as that already given in fig. 8. From the latter figure it will be seen that the steady lamp wattage, and therefore the steady temperature, is greatest at F and decreases as it passes through D to A. The normal current and lamp voltage correspond to the point E, which lies on the nearly vertical portion of the characteristic; it will be remembered that this portion corresponds to complete volatilisation of the mercury. As soon as it passes below D, the steady lamp temperature is insufficient to keep all the mercury in a state of vapour, so that a certain amount of condensation takes place. Over the portion AD some liquid mercury is always present and the vapour density decreases steadily from D towards A. As long as some mercury is present as liquid, any rise in lamp watts (or temperature) will result in further evaporation, with a corresponding increase in vapour density; conversely, any reduction in the temperature will cause a decrease of vapour density.

If the vapour density were kept strictly constant, the current-lamp voltage characteristic would be of the form shown by the line FDC. It will be seen that, as in the case of an arc, the potential between the electrodes decreases as the current increases. This is just the opposite of what occurs with a pure resistance.

At each point of the steady characteristic AD, there will be a corresponding current-voltage curve. These form a family of curves, whose shapes are similar to those drawn at FDC and GAH in fig. 13. Each of these curves, moreover, corresponds to a definite value of the vapour density, so that any one curve will only apply so long as this density remains constant. This will be the case provided

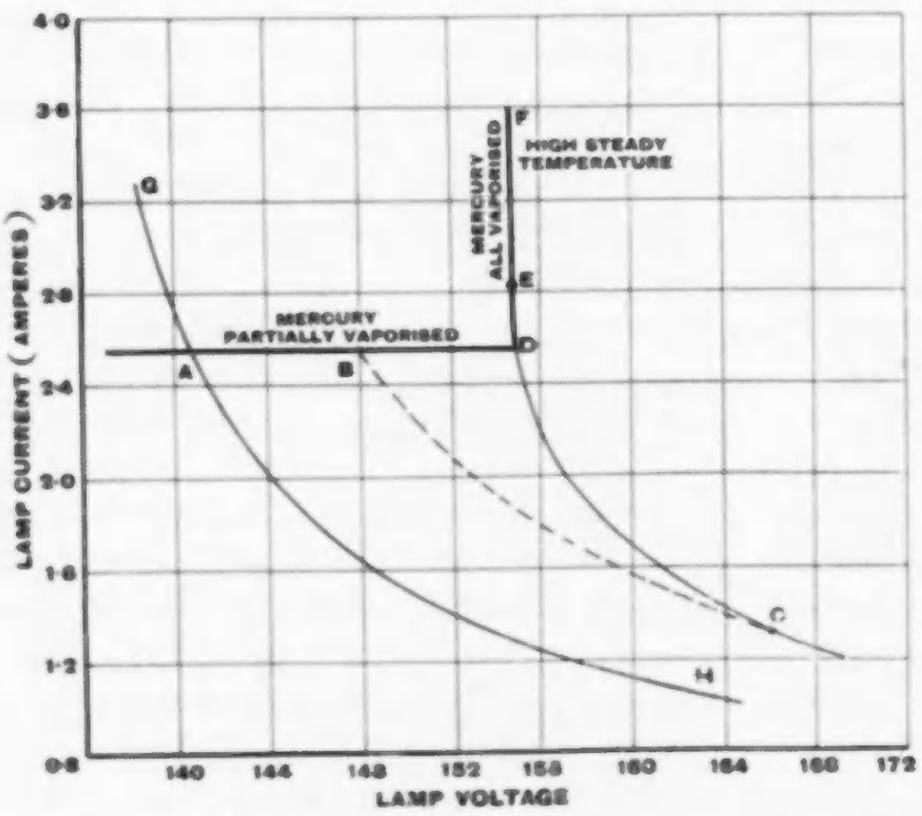


Fig. 13.—Instantaneous current-voltage characteristics for the lamp alone.

that any change producing an alteration in the current takes place very suddenly, but if the change is slow enough the lamp temperature, and therefore the vapour density, will continually adjust itself during the change. In this case the current and lamp voltage will follow the steady characteristic

AD. It will be seen that this forms the connecting link between the whole family of curves for different constant vapour densities. Since these latter curves can only be obtained in practice by suddenly changing the current and then observing the instantaneous change in lamp voltage, they are called the instantaneous characteristics.

When all the mercury remains volatilised, it obviously makes no difference if the current changes slowly or rapidly, because the vapour density remains constant. It is seen, therefore, that the portion of the curve DF forms both the steady and the instantaneous characteristic in this case.

Fig. 8 shows that the wattage corresponding to the point D is about 365 for an average lamp, while that corresponding to the normal conditions, represented by the point E, is 400. Now suppose that by altering the air gap of the choke, or by changing the mains voltage, we vary the current through the lamp, which is assumed to be burning normally at 400 watts, then, provided that the change does not reduce the lamp wattage below 365, the lamp current and voltage values will follow the line from E up towards F or down towards D. Since no mercury is condensed, it will not matter if the change is fast or slow. On the other hand, if the change is such as to reduce the final steady lamp wattage below 365 (the point D), the lamp current and voltage values will follow the line EDA if the change is slow; let it be supposed that the change is such that the final conditions are represented by the point B. It will be seen that the lamp voltage never rises above 155 volts, and the current does not fall below 2.56 amperes. If the change were made suddenly, however, then the current and lamp voltage would follow the instantaneous characteristic EDC, and their values immediately after the change would thus be 1.3 amperes and 164 volts. They will not remain for more than an instant at these values, because some mercury will start to condense and, as the lamp gradually cools to the new temperature, they will follow some curve, such as is shown dotted, from C back to B. This end point is, of course, the same as that corresponding to the case when the change took place slowly.

The important practical result of all this is that whenever the current is slowly reduced to below the normal burning value, the lamp voltage will remain nearly constant at first and then fall while, if the change is very sudden, it will rise rapidly at first and then fall.

As regards the instantaneous characteristic curve connecting the potential across the lamp with supply voltage, in this case the curves are no longer a function of the lamp alone but depend to some extent upon the choke design.

Fig. 14 shows both the steady and instantaneous characteristics for an average lamp, when the choke has been set for 230 volts. The steady characteristic is composed of the lines AD and DF; the point E again corresponds to the normal burning conditions and, as before, the portions AD and DF correspond respectively to partial and complete vaporisation of the mercury.

If the mains volts are reduced slowly the lamp volts remain practically constant until the point D, corresponding to a mains voltage of 222, is reached.

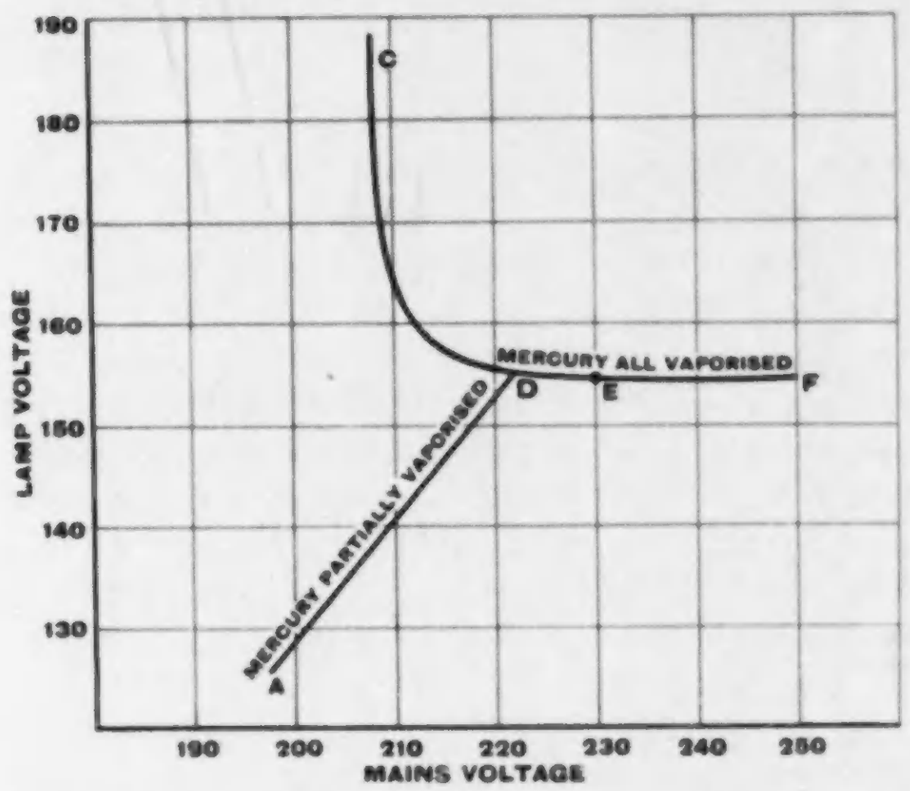


Fig. 14.—Instantaneous and steady lamp voltage—mains voltage characteristics. Choke set for 230 volts.

After this, any further reduction in the supply voltage results in a fairly rapid drop in the potential across the lamp. This corresponds to the sloping line DA.

If, however, the supply voltage were reduced very suddenly, the lamp voltage would follow the instantaneous characteristic EDC. This curve soon becomes extremely steep and, in fact, if the mains voltage were dropped suddenly from 230 to 207, for example, the potential across the lamp would rise considerably. The potential necessary to maintain the discharge will thus be higher than that available and this means that the lamp will go out.

The mains voltage corresponding to the steep portion of the instantaneous characteristic can be taken as the limiting value below which the lamp will be extinguished, if the drop is sudden.

In practice it turns out that the mains voltage may be reduced by any reasonable amount, if the rate of fall does not exceed about 15 volts per minute. Although for a single average lamp, on a supply of 230 volts, the allowable *sudden* drop is about 22 volts, nevertheless, in view of supply variations and small differences which may occur between different lamps, the allowable sudden drop, for an installation, should not be taken as more than 10 to 15 volts. If the supply is 240 volts these figures may be increased by nearly 10 volts.

The "Chance" Sand Flotation System of Cleaning Coal.

By H. L. WOOD, B.Sc.
Fraser & Chalmers Engineering Works of The General Electric Co., Ltd.

THE "Chance" sand flotation process for cleaning coal has since its introduction met with remarkable success in the United States of America. Although the first commercial plant was only erected in 1921, over 40,000,000 tons of coal are now being cleaned annually by plants using this process, while it is interesting to note that the figures for 1932 show an increase in the amount of coal dealt with by "Chance" plants, despite the total American output of coal being considerably less than in previous years.

The "Chance" process of cleaning coal has now been introduced into this country by Fraser & Chalmers Engineering Works, who in order to demonstrate its high efficiency, and to overcome the natural prejudices encountered in a new development of this nature, have built at Erith a complete test plant on a commercial scale. Innumerable bulk tests have been carried out on this plant with unvarying success on coals of widely differing washability characteristics.

BASIC PRINCIPLES.

The process is a commercial application of the float and sink method of testing coal, a fluid mass of sand and water being employed as the high density medium. The nature and characteristics of this fluid mass can be clearly demonstrated by the use of a simple model of the type shown in fig. 1. This consists of a circular water box spigoted at the top to allow a glass tube of suitable diameter to be cemented into it as shown. A number of small holes are drilled in the top plate of the water box to distribute the water evenly to the glass tube, and this water is controlled by valve A. The model should be about a third filled with clean washed sand which, at rest, is at the level V. On opening the valve A, the sand will be hydraulically agitated to form the sand and water fluid mass, and the top of the sand and water line will rise to a level, say W, and above that level there will be clean water. The perfect fluidity of the sand and water mixture can be best appreciated by placing a hand in the model and shutting the eyes, when it is impossible to tell, if the fingers are kept still, whether the hand is in water or sand and water.

If a piece of coal is now dropped into the model it will sink rapidly through the clear water until it reaches the sand and water fluid mass, where it will float like an iceberg in the sea. Should a piece of stone or shale, however, be dropped in, it will sink right through the fluid mass and come to rest on the perforated top of the water box.

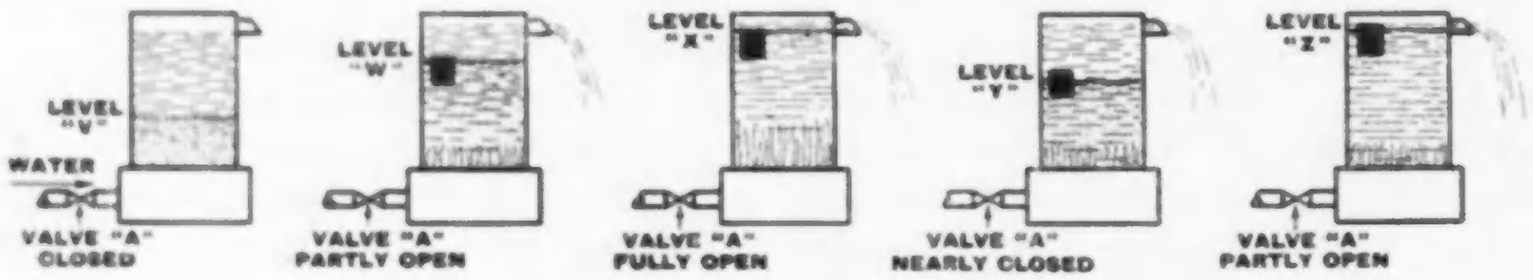


Fig. 1.—Diagrams illustrating sand flotation principle.

The density of the fluid mass in the model can be readily changed by altering the amount of agitation water admitted by the valve A. Thus to reduce the density the amount of water should be increased and the sand and water line will rise to (say) level X. It will be then seen that the piece of coal is floating very much lower in the sand and water, or may even sink through it if an excessive increase has been made in the amount of agitation water. In other words, the sand and water mixture has been diluted by more water and its average density materially reduced.

Alternatively, if the water quantity had been reduced instead of increased, the sand and water level would have fallen to say level Y, and as its density would be considerably higher the piece of coal would float with more of its bulk projecting into the clear water.

The sand and water level is now brought back to the original position W by means of valve A, and the bulk of the piece of coal projecting above the sand and water line into the clear water carefully noted. Sand is added to bring the sand level to the line Z and it will be seen that the piece of coal is floating in the same relative position to the sand and water line as it was before the sand was added. Thus the addition of sand has not increased the density in any way and has only raised the level of the sand and water line.

As a result of these experiments it is obvious that the density of the fluid mass is purely dependent on the amount of agitation water and is entirely independent of the amount of sand in the system. Further, within the designed limits this density can be easily and readily controlled at will.

Another interesting point may be observed during the last experiment. When the extra sand is added, this falls quickly through the clear water to the sand and water line, showing that the upward velocity of the water is considerably less than the falling velocity of sand in water. This is a most important point, as, based on the erroneous assumption that these two velocities are equal, it is easy to prove that a "Chance" washer cannot deal with coal below about $\frac{3}{16}$ in. Actually in practice the limit occurs at the point at which the sand and coal can be effectively separated by wet screening.

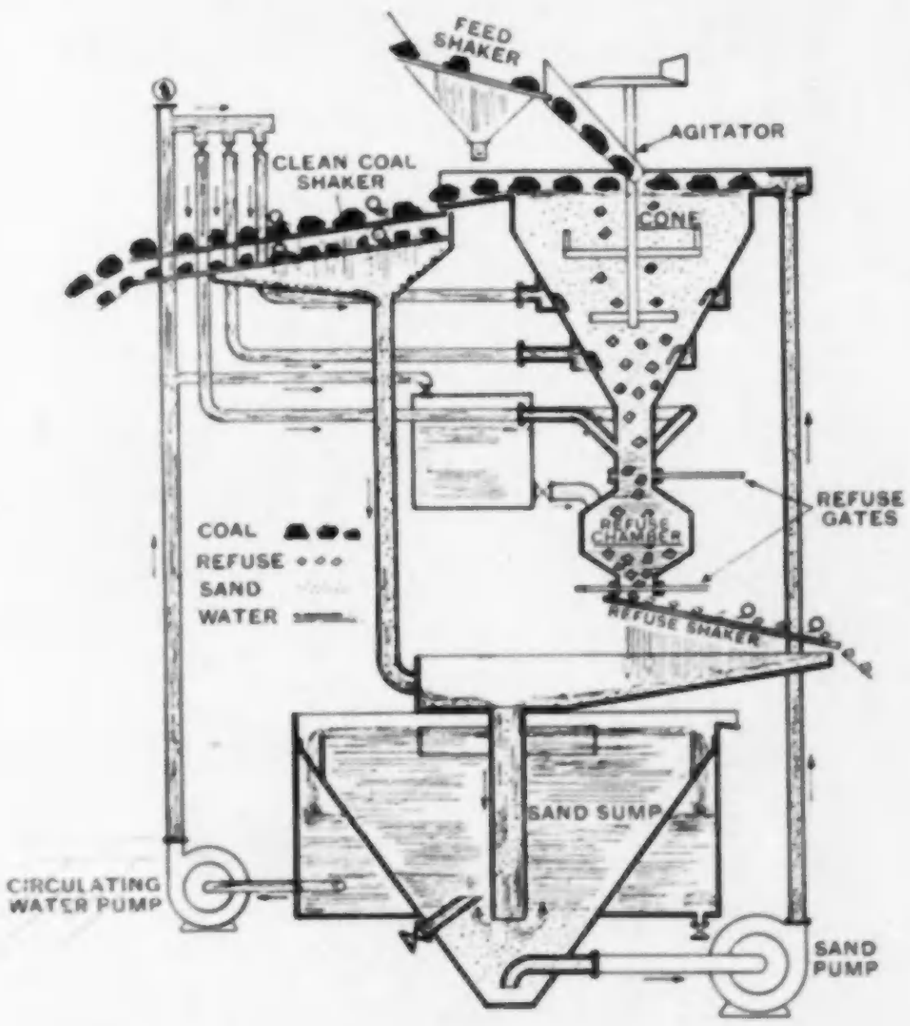


Fig. 2.—Diagrammatic arrangement of Fraser & Chalmers "Chance" coal washing plant.

It may seem that these preliminary experiments with the model have been unduly stressed, but a clear understanding of the basic principles makes it much easier to follow the operation of an actual "Chance" washery.

THE EQUIPMENT AND ITS OPERATION.

A diagrammatic arrangement of a "Chance" washery is seen in fig. 2. Here the glass tube of the model has been replaced by a "Chance" cone, and the agitation water, instead of coming through the water box, is introduced through two or more rings at the side of the cone and also into the classifier column at the base of the cone. The raw coal, after de-dusting, is fed into the cone, and the clean coal is carried round on the top of the fluid mass to the exit weir, where it flows out of the cone on to the clean coal shaker screen as shown. Sand and water is overflowed from the cone to carry the clean coal out to the clean coal screen, and the first section of this screen is used for de-watering and de-sanding. The sand and water are collected and returned to the main sand sump. The remainder of the clean coal shaker is used for sizing the coal in the normal manner.

Fig. 3.—Fraser & Chalmers "Chance" washery at Charlesworth's Newmarket Colliery near Wakefield. View shows base of cone, classifier column, refuse chamber and shaker.

Mention should be made here of the automatic de-sanding action which takes place on this screen. Reverting again to the model, if a piece of coal is lifted out carefully it will be found to be covered with sand, but if it is raised into the clear water zone and turned over once before withdrawal, it will be seen to be completely free from sand. Applying this to the actual washery, the coal is carried out

of the cone in a sand and water stream, which has a layer of clear water above it. On reaching the clean coal shaker the sand and water pass through, whilst the coal rolls on through the clear water layer, where it is automatically de-sanded. Without

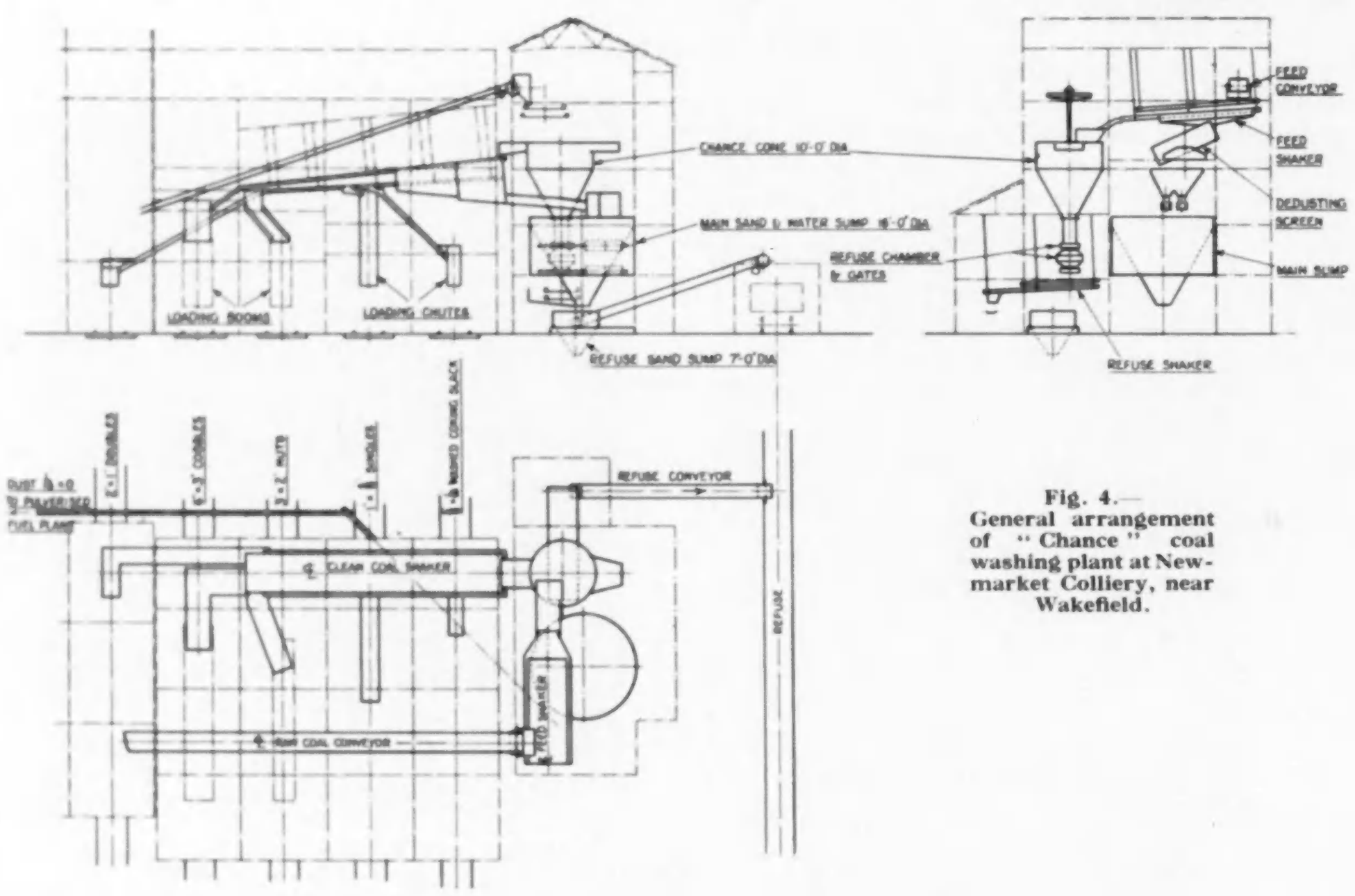


Fig. 4.—General arrangement of "Chance" coal washing plant at Newmarket Colliery, near Wakefield.

any further provision little or no sand would appear with the clean coal, but to ensure perfect freedom from sand, and also to improve the appearance of the coal, water sprays are fitted to this screen, the make up water being brought in on the last of these.

The refuse which sinks through the fluid mass collects in the classifier column and the base of the cone, whence it is evacuated in the following manner. Between the classifier column and the refuse shaker a refuse chamber is interposed, fitted with top and bottom refuse gates. These gates are opened and shut by means of air-operated thrust cylinders.

Assuming that the refuse chamber is full of water the cycle of operations is as follows. The top gate is opened by the thrust cylinder and remains open for a predetermined time. During this time the refuse and a certain amount of sand enter the refuse chamber. As soon as the top gate is shut the bottom refuse gate opens and discharges the contents of the refuse chamber on to the refuse shaker screen. The sand and water after passing through the screen are collected and returned to the main sand sump, whilst the refuse is discharged from the screen for disposal or re-treatment. The bottom refuse gate is also open for a pre-determined time, and as soon as it is closed a water valve opens to fill the refuse chamber with water. When the chamber is full a pressure switch is tripped which shuts the water-filling valve and allows the top

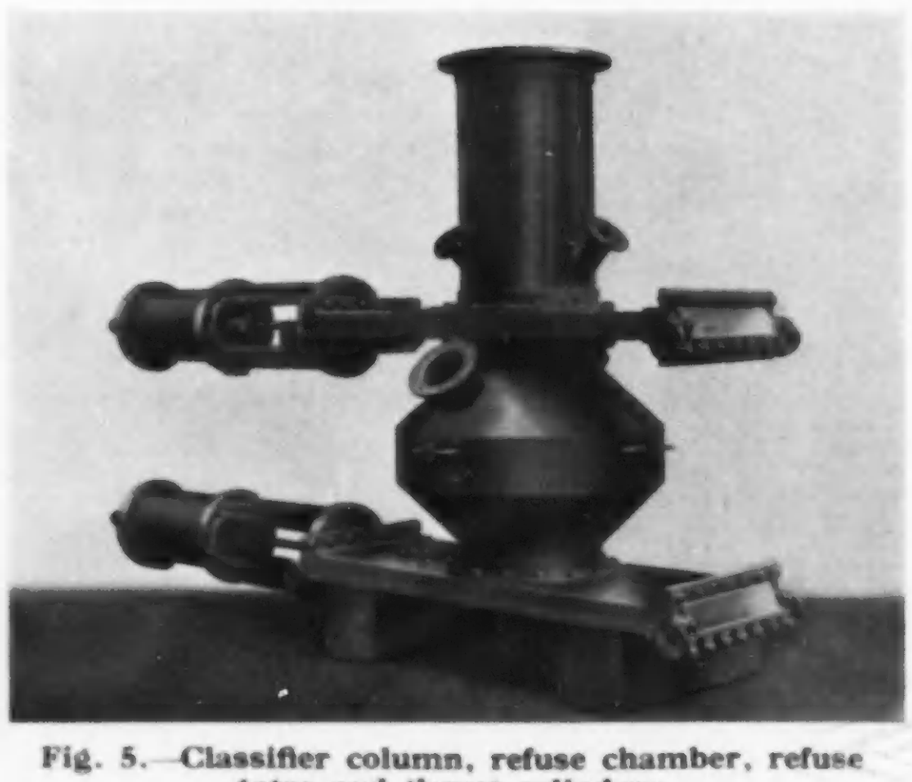


Fig. 5.—Classifier column, refuse chamber, refuse gates and thrust cylinders.

gate to open and recommence the cycle. The whole of this equipment is automatic and is interlocked to prevent both gates from opening at once, and the time of the cycle can be adjusted to deal with the maximum rate at which refuse is likely to be fed into the plant. There is no need to alter the timing

for lesser rates of refuse as the efficiency is not affected in any way if the chamber has little or no refuse in it.

Reverting again to the agitation water, it will be seen that a control valve is provided to regulate the amount of agitation water that is allowed to enter

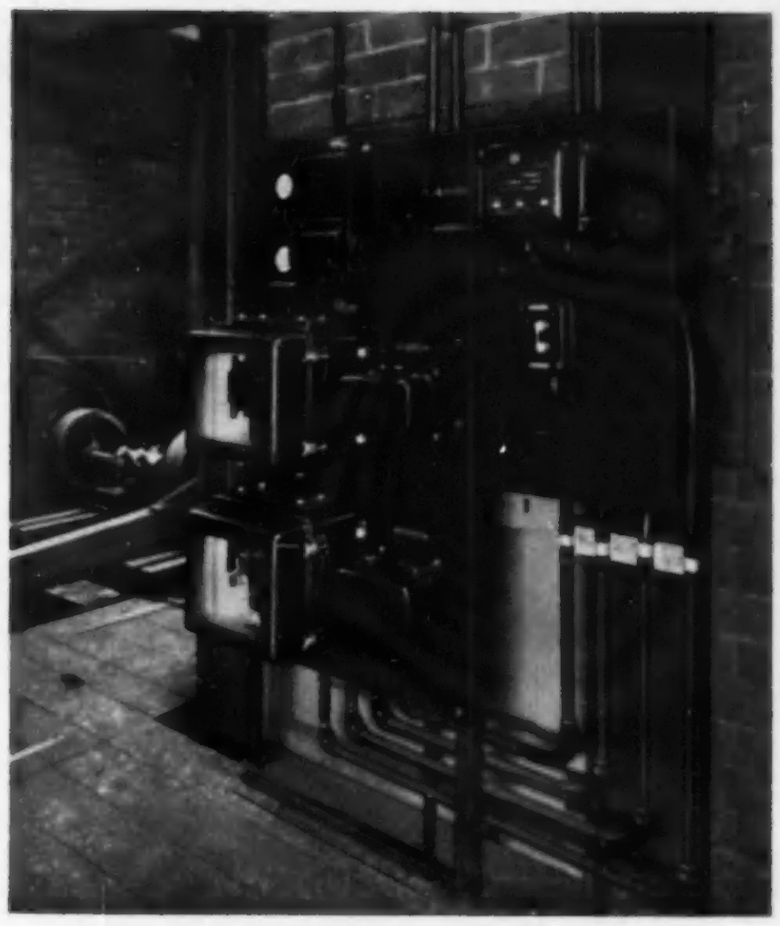


Fig. 6.—Control panel for refuse gate operation.

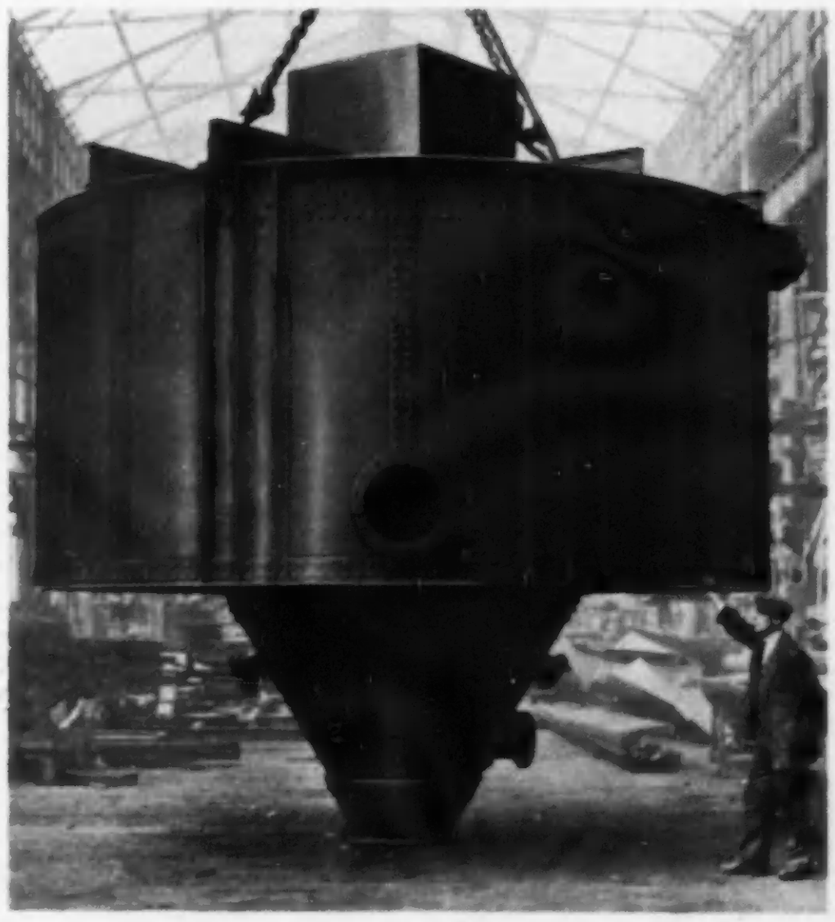


Fig. 7.—Main sand pump.

at each point. A given circulating water pressure and a given setting on each of these control valves will always maintain the same density in the cone.

In addition to hydraulic agitation, a revolving mechanical agitator is used in an actual "Chance" washer, and this agitator has three important functions to perform: it prevents the sand from banking up on the side of the cone, it assists the flow of coal round from the feed chute to the exit weir, and finally it helps to keep the sand and water intimately mixed.

References have been made earlier to the return of the sand and water from the clean coal and refuse

Fig. 8.—Refuse sand pump.

shakers. From the diagrammatic arrangement (fig. 2) it will be seen that the mixture is carried by a pipe to the lower portion of the main sand sump. This sump is designed to give a very low upward velocity so that the sand remains at the bottom of the sump, whilst the water overflows from the sand sump into the water sump.

The circulating water pump suction is taken from this water sump, the water being used for agitation, refuse chamber filling, etc. The concentrated mixture of sand and water is pumped back to the "Chance" cone from the bottom of the sand sump by a special sand pump. This is, of course, necessary, as sand and water is used as the conveying medium to carry the coal out of the cone, and unless this sand was returned to the cone the level of the sand and water would quickly drop to such a point that coal would not be carried from the cone on to the clean coal shaker.

As perfect de-dusting of the raw coal is not possible, provision has to be made to deal with this small amount of undersize and to prevent its accumulation in the system. The fine coal and refuse that is not caught by the clean coal shaker and refuse shaker respectively is, of course, carried with the sand and water to the main sand sump. This, in effect, acts like another "Chance" cone run at a high density, and this fine material floats on the top of the

sand and water mixture. On shutting down the sand settles at the bottom of the sand sump with the fine coal on top of it and the water above that. By

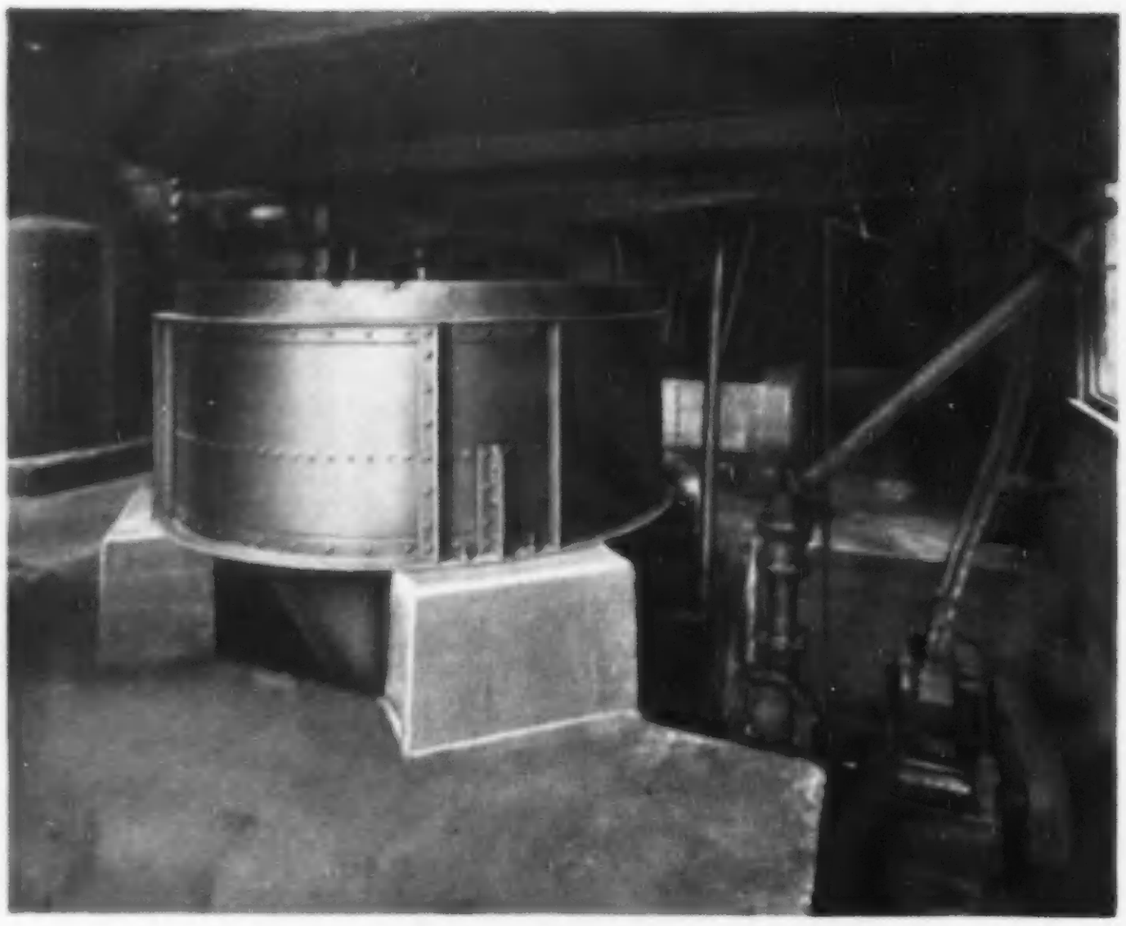


Fig. 9.—Refuse sand sump and pump.

reference to fig. 2 a slurry discharge pipe, fitted with a valve, will be noticed projecting into the sand sump, the level of the slurry pipe being just above

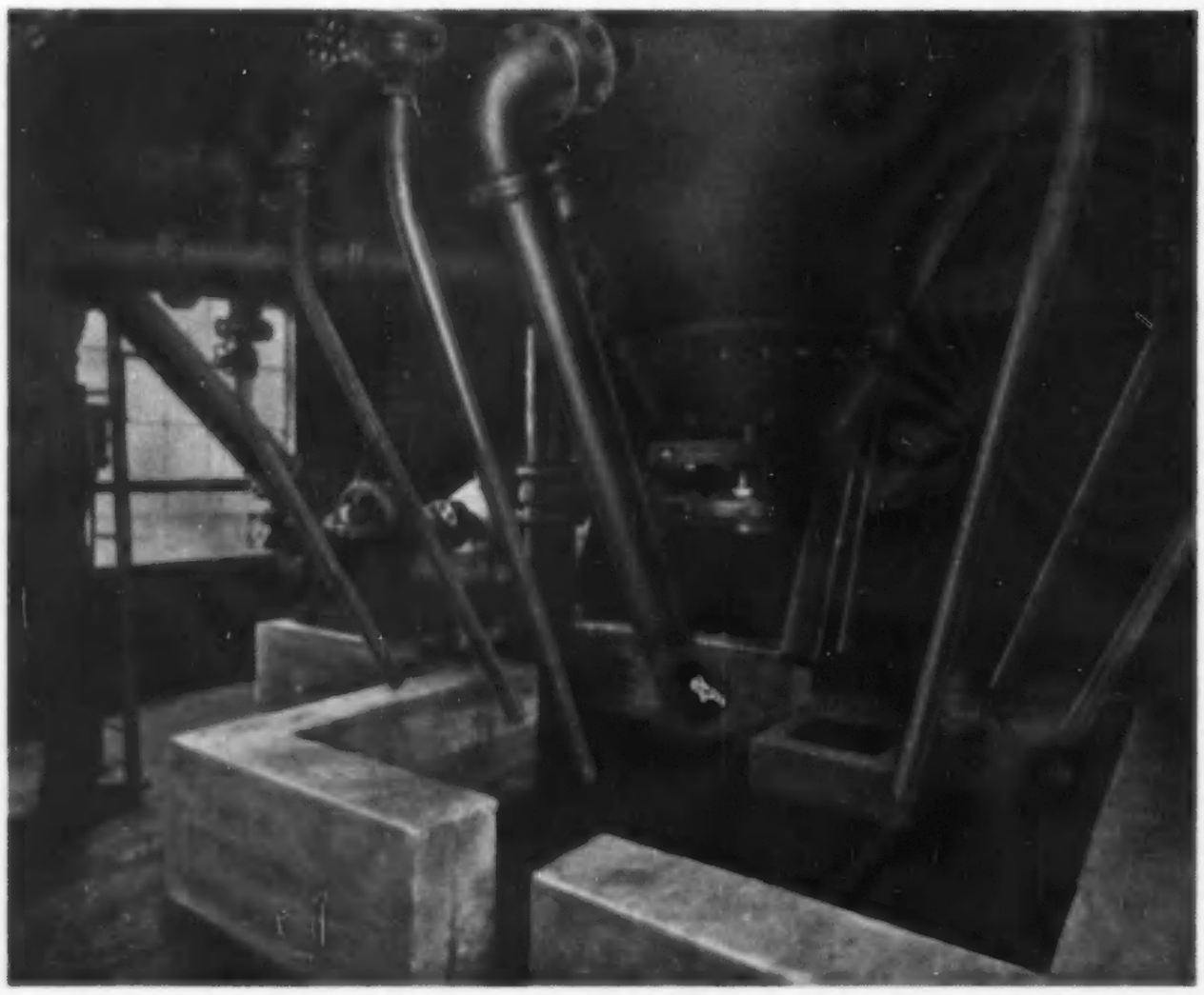


Fig. 10.—Bottom of main sand sump, showing silt drains and circulating water pump.

the sand level when the plant is at rest. On this valve being opened at the end of each shift the fine material is run out of the system.

The very finest slurry which will not settle in the sand sump, is, of course, carried to the water sump, where it either settles and is removed by the slurry drains as required, or is carried to waste by the small amount of water that is continually overflowed to keep the water free from contamination. On account of the fact that there is no measurable breakage in a "Chance" cone the amount of solids carried away by this overflow water is remarkably low.

To reduce the amount of fines to be dealt with by the above methods to very small quantities, a certain proportion of the water discharged from the cone is by-passed over a slurry screen mounted alongside the refuse shaker.

COAL WASHER INSTALLATION AT NEWMARKET COLLIERY, WAKEFIELD.

In figs. 3 to 11 is shown a 100-ton per hour "Chance" washer recently started up at Newmarket Colliery, Wakefield, which is dealing with the whole of the pit out-put below 6in. in size.

The jigging screens on to which the tipplers discharge are, therefore, fitted with 6-in. round hole screen plates, and the throughs from this screen are delivered to a belt conveyor, which conveys them to the "Chance" washery, the coal above 6in. being discharged to the existing lump picking belts. The coal on arrival at the washery is delivered to a shaker screen. The shaker removes all material below $\frac{5}{8}$in., the undersize being delivered to a high-speed vibrating screen, which is fitted with a $\frac{1}{16}$-in. screen. All the coal from 6in. to $\frac{1}{16}$in. is delivered to the "Chance" cone. The minus $\frac{1}{16}$-in. to 0 coal is taken by a system of Redler conveyors to a Fraser & Chalmers pulverized fuel plant arranged to fire four Lancashire boilers. The clean coal passes out of the cone to the clean coal shaker screen, the first section of which is used for de-watering and de-sanding, the remainder for sizing in the normal manner. The refuse, after leaving the refuse screen, is fed to a short belt conveyor, which delivers it to wagons on a suitable track. In this installation the main sand and water sump is placed only slightly below the clean coal shaker, and a refuse sand sump is arranged to take the small amount of sand and water that comes from the refuse shaker. This refuse sand sump is merely a surge tank from which

sand and water is pumped to the main sand and water sump for separation. This arrangement, which is standard on almost all commercial units, considerably reduces the head on the main sand and water pumps.

TEST PARTICULARS.

A very large number of tests on widely differing coals have been carried out on the "Chance" washer installed at Erith (fig. 12), but in the scope of this article it is only possible to give a brief resumé of some of the results.

The accompanying table shows the results of the sink and float examination of a South Yorkshire coal prior to washing, and from which it will be seen that a yield of 79.09 per cent could be expected with 2.93 per cent of ash, whilst the 20.91 per cent of refuse discarded should have an ash content of 67.38 per cent, the ash content of the raw coal being 16.40 per cent.

The table also gives the actual clean coal and refuse ash contents obtained when testing this coal on the "Chance" washer, from which it will be seen that the theoretical perfect separation has been achieved. The sink and float figures show that this is an easy coal to wash. A more difficult coal was that sent for test by the South Yorkshire colliery, whose "Chance" washer has already been described. In this case the raw coal had an ash content of 17.24 per cent, and the clean coal, after washing, had an ash content of 4.03 per cent, and the refuse 72.92 per cent. This test was carried out at a density of 1.50, and during the test numerous samples of coal and refuse were tested in a density of 1.50; on these tests there were no measurable sinks in

Fig. 11.—Top of cone showing feed; on the left is a sink and float machine for testing coal and refuse.

FLOAT AND SINK TABLE.

Ash Contents and Weight Percentages.

PRODUCT TREATED: SOUTH YORKSHIRE COAL.

SIZE.	Float at 1.30 Sp. Gr. Sink at — Sp. Gr.			Float at 1.35 Sp. Gr. Sink at 1.30 Sp. Gr.			Float at 1.40 Sp. Gr. Sink at 1.35 Sp. Gr.			Float at 1.45 Sp. Gr. Sink at 1.40 Sp. Gr.			Float at 1.50 Sp. Gr. Sink at 1.45 Sp. Gr.			Float at — Sp. Gr. Sink at 1.50 Sp. Gr.			RAW COAL.		
	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %
Not Sized	64.18	1.90	1.219	11.37	5.94	0.675	3.54	12.10	0.428	0.88	17.16	0.151	0.74	18.64	0.138	19.29	71.47	13.79			
	‹——— 79.09% Yield @ 2.93% Ash ———›									‹——— 20.91% Refuse @ 67.33% Ash ———›											
	Ash Analyses of Products after Washing:																				
	CLEAN COAL ‹——— 2.88% Ash ———›									‹——— REFUSE 67.52% Ash ———›									‹— RAW COAL. 16.40% Ash —›		

PRODUCT TREATED: TRANSVAAL COBBLES.

SIZE.	Float at 1.40 Sp. Gr. Sink at — Sp. Gr.			Float at 1.45 Sp. Gr. Sink at 1.40 Sp. Gr.			Float at 1.50 Sp. Gr. Sink at 1.45 Sp. Gr.			Float at 1.55 Sp. Gr. Sink at 1.50 Sp. Gr.			Float at — Sp. Gr. Sink at 1.55 Sp. Gr.			Float at — Sp. Gr. Sink at — Sp. Gr.			RAW COAL.		
	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %	Wt. %	Ash %	Cum. Ash %
3½" × 1½"	39.55	8.22	3.25	16.87	8.20	1.38	12.99	17.60	2.28	7.66	19.14	1.47	22.93	39.79	9.12						
	‹——— 69.41% Yield @ 9.95% Ash ———›									‹—— 30.59% Refuse @ 34.62% Ash ——›											
	‹—— 56.42% Yield @ 8.20% Ash ——›						‹——— 43.58% Refuse @ 29.53% Ash ———›												‹— 17.50% Ash —›		

PRODUCT TREATED: NATAL MIXED SMALLS.

2" × ⅜"	60.81	7.21	4.38	14.12	13.64	1.92	6.62	19.26	1.27	5.22	22.32	1.16	13.23	45.48	6.02						
	‹——— 74.93% Yield @ 8.47% Ash ———›						‹——— 25.07 Refuse @ 33.27% Ash ———›														
	‹——— 81.55% Yield @ 9.26% Ash ———›									‹—— 18.45% Refuse @ 38.86% Ash ——›									‹— 14.75% Ash —›		

the coal or floats in the refuse at that gravity, thus showing that a perfect cut had again been made at the required density.

Turning to rather more difficult coals, a test was carried out on South Wales anthracite, and the sink and float log for this test showed 0.35 per cent, 0.70 per cent and 0.73 per cent respectively on the three samples of clean coal taken, whilst the amount of float in the refuse, taken at the same density, showed respectively 0.10 per cent and 0.07 per cent, the ash content of the washed anthracite in this case being 3.23 per cent, whilst the ash content of the refuse amounted to 74.41 per cent.

Another South Wales coal, which is notoriously difficult on account of the presence of clay, showed an average of 0.2 per cent of sink in the clean coal, and 0.1 per cent of float in the refuse, when tested at the operating density of the cone.

Turning to still more difficult coals, the table shows the sink and float analysis for an extremely difficult Transvaal coal, the size in this case being cobbles. For this sample a cut was made at 1.50 density, and again no measurable sink was obtained in the clean coal or float in the refuse when tested at that density.

The characteristics of another South African coal are also given in the table. In this case the coal came from Natal, and the clean coal when tested had 0.4 per cent of sink and the refuse 0.5 per cent of float at the operating density. Thus on every test a practically perfect cut was made at the required density, or, in other words, perfect separation or washing was obtained.

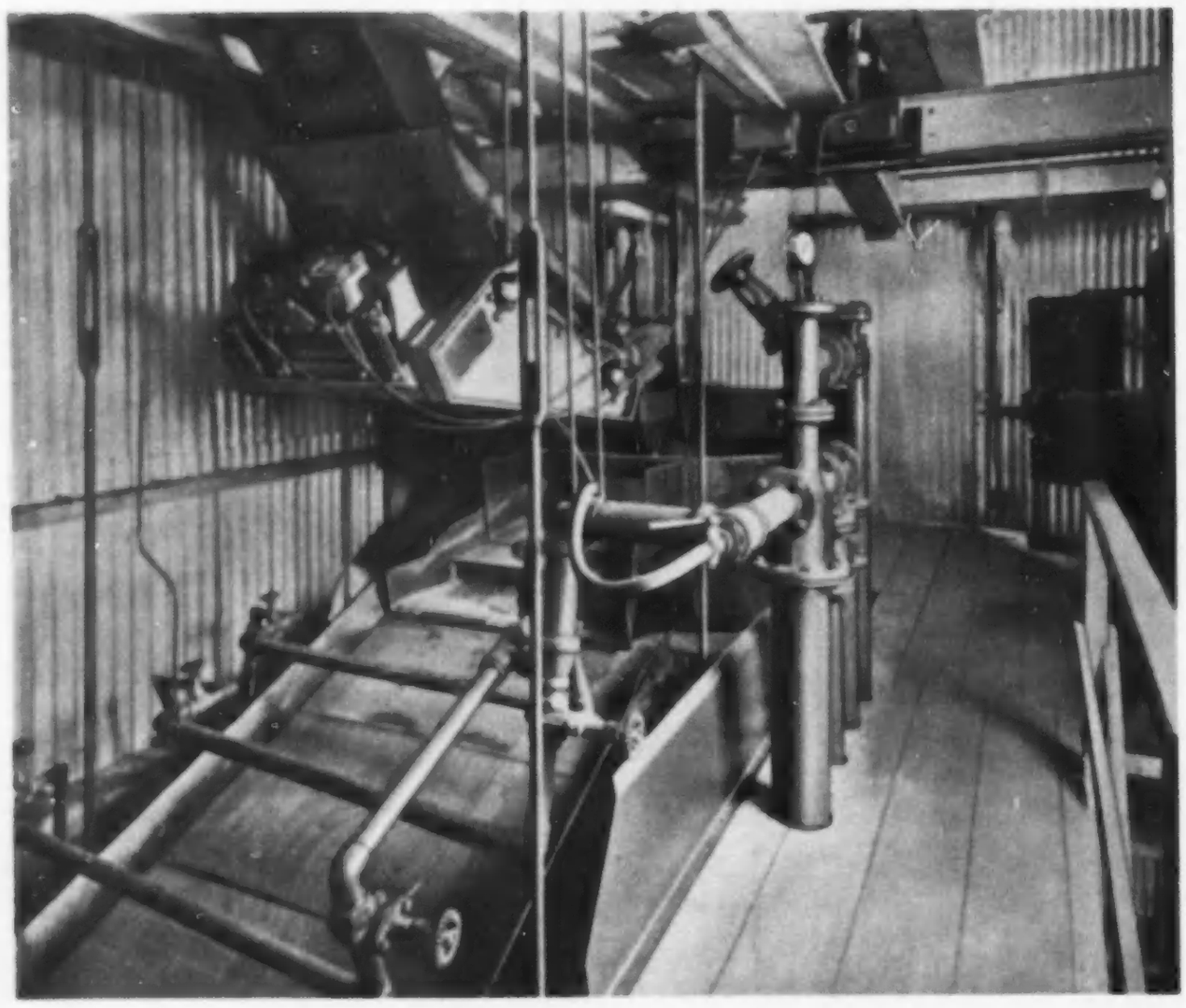
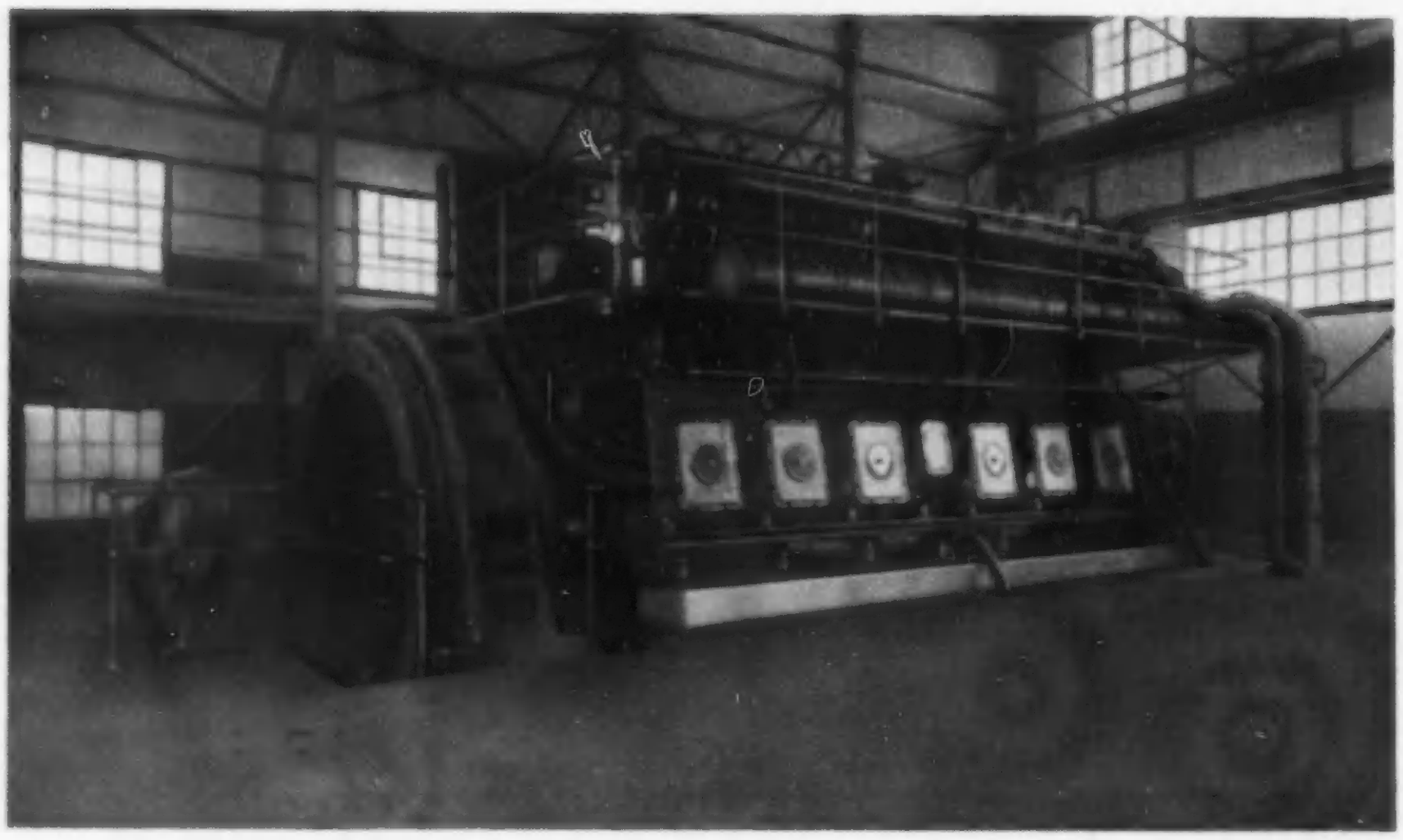


Fig. 12.—"Chance" coal washing test plant at Fraser & Chalmers' Engineering Works, Erith, Kent, showing top of cone with feed screens and clean coal screens.

Diesel-engine driven Alternators for Macao.



A 6-cylinder Fraser & Chalmers' heavy oil engine driving a 3,000 volt, 1,500 kVA, 3 phase, 50 cycle alternator at 300 r.p.m. This set is installed in the Generating Station of the Macao Electric Co., for whom a similar set has recently been exported.

Floodlighting.

PART II.

By THOMAS E. RITCHIE, A.M.I.E.E.
Chief Illuminating Engineer of The General Electric Co., Ltd.

FROM the point of view of the lighting engineer the most interesting and unusual of many excellent examples of floodlighting was that of Buckingham Palace, the facade of which, as it appeared nightly during the period of the illuminations, is shown in fig. 19.

The designing of the scheme of illumination was complicated by the fact that regard had of necessity to be paid to certain governing considerations. For instance it was stipulated that the forecourt of the Palace should be kept free from anything which might constitute an obstruction to the heavy traffic incidental to the holding of the Royal Courts, and that the whole of the floodlighting equipment should be located within as short a distance as possible from the inside edge of the boundary railings. This prevented the effective use of projectors other than those of the long range, narrow angle type. Again, the fact that the Court was in residence until within ten days of the opening date for the illuminations, rendered it impossible to undertake such preliminary tests and experimental trials as were performed in respect of every other installation of magnitude.

Part I *of this article appeared in the issue of the G.E.C. Journal dated November* 1932, *Vol.* III, *No.* 4, *and dealt with the fundamental principles underlying the new science of floodlighting.*

Part II, *which is published here, describes the actual methods adopted to obtain the many and varied effects which can be produced ; some account is also given of the type of equipment used in some well known floodlighting installations.*

The Palace faces East by North and, therefore, as is shown by fig. 1, is only seen under direct sunshine during the early morning hours. Inspections made at intervals throughout the fore-noon made it evident that the facade as a whole appeared most pleasing when the emphasis of the sunshine was provided by rays falling upon the building from the left side. That this should have proved the case is perhaps not surprising when it is considered that the effect created by such directional lighting (shown by fig. 20) is precisely that invariably depicted by artists renowned for their skill in the production of architectural perspectives. This point will be appreciated by those familiar with the work in this particular field of, for example, Cyril Farey, William Walcot and Sir John Burnett.

For this reason, and in view of the relatively slight projection of the ornamental mouldings and other features of the elevation upon which it was desired to obtain the maximum play of light and shade, it was decided that when floodlighting, the beams of light from the projectors should be directed as far as possible upon the face of the building from the left hand side, although it was

Fig. 19.—A night view of Buckingham Palace floodlighted by 188 projectors.

the coal or floats in the refuse at that gravity, thus showing that a perfect cut had again been made at the required density.

Turning to rather more difficult coals, a test was carried out on South Wales anthracite, and the sink and float log for this test showed 0.35 per cent, 0.70 per cent and 0.73 per cent respectively on the three samples of clean coal taken, whilst the amount of float in the refuse, taken at the same density, showed respectively 0.10 per cent and 0.07 per cent, the ash content of the washed anthracite in this case being 3.23 per cent, whilst the ash content of the refuse amounted to 74.41 per cent.

Another South Wales coal, which is notoriously difficult on account of the presence of clay, showed an average of 0.2 per cent of sink in the clean coal, and 0.1 per cent of float in the refuse, when tested at the operating density of the cone.

Turning to still more difficult coals, the table shows the sink and float analysis for an extremely difficult Transvaal coal, the size in this case being cobbles. For this sample a cut was made at 1.50 density, and again no measurable sink was obtained in the clean coal or float in the refuse when tested at that density.

The characteristics of another South African coal are also given in the table. In this case the coal came from Natal, and the clean coal when tested had 0.4 per cent of sink and the refuse 0.5 per cent of float at the operating density. Thus on every test a practically perfect cut was made at the required density, or, in other words, perfect separation or washing was obtained.

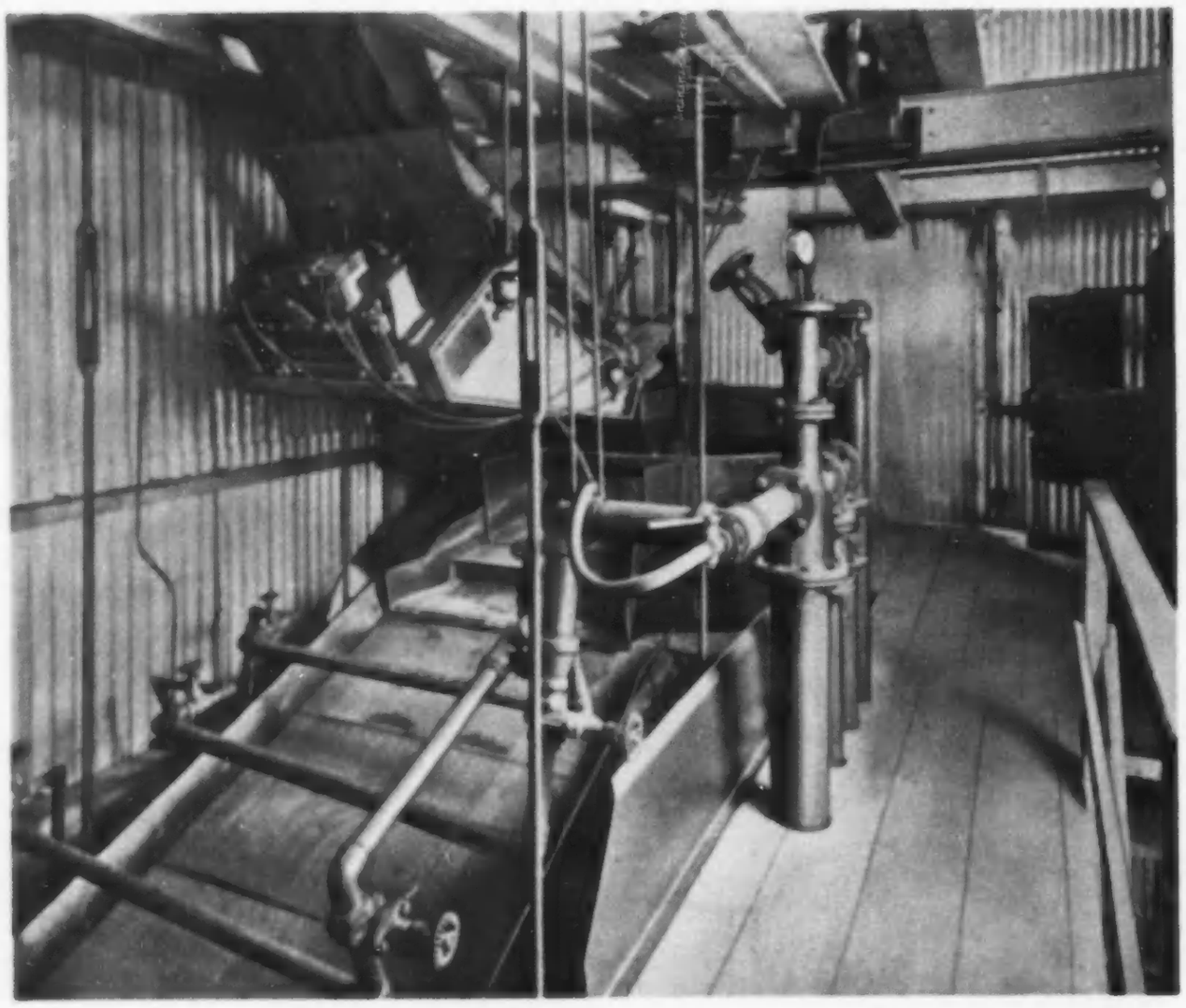
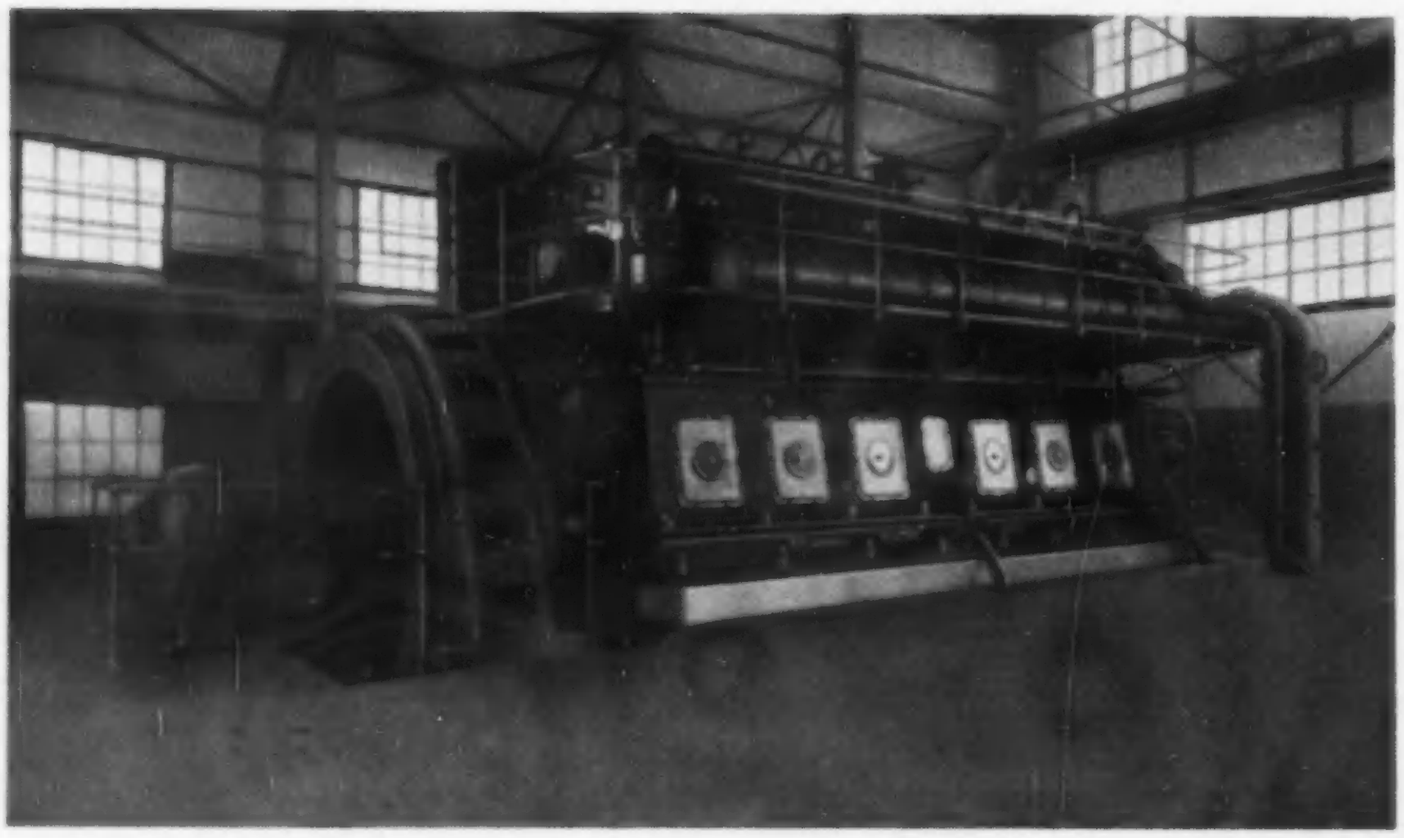


Fig. 12.—"Chance" coal washing test plant at Fraser & Chalmers' Engineering Works, Erith, Kent, showing top of cone with feed screens and clean coal screens.

Diesel-engine driven Alternators for Macao.



A 6-cylinder Fraser & Chalmers' heavy oil engine driving a 3,000 volt, 1,500 kVA, 3 phase, 50 cycle alternator at 300 r.p.m. This set is installed in the Generating Station of the Macao Electric Co., for whom a similar set has recently been exported.

Floodlighting.

PART II.

By THOMAS E. RITCHIE, A.M.I.E.E.
Chief Illuminating Engineer of The General Electric Co., Ltd.

Part I *of this article appeared in the issue of the G.E.C. Journal dated November* 1932, *Vol.* III, *No.* 4, *and dealt with the fundamental principles underlying the new science of floodlighting.*

Part II, *which is published here, describes the actual methods adopted to obtain the many and varied effects which can be produced ; some account is also given of the type of equipment used in some well known floodlighting installations.*

FROM the point of view of the lighting engineer the most interesting and unusual of many excellent examples of floodlighting was that of Buckingham Palace, the facade of which, as it appeared nightly during the period of the illuminations, is shown in fig. 19.

The designing of the scheme of illumination was complicated by the fact that regard had of necessity to be paid to certain governing considerations. For instance it was stipulated that the forecourt of the Palace should be kept free from anything which might constitute an obstruction to the heavy traffic incidental to the holding of the Royal Courts, and that the whole of the floodlighting equipment should be located within as short a distance as possible from the inside edge of the boundary railings. This prevented the effective use of projectors other than those of the long range, narrow angle type. Again, the fact that the Court was in residence until within ten days of the opening date for the illuminations, rendered it impossible to undertake such preliminary tests and experimental trials as were performed in respect of every other installation of magnitude.

Fig. 19.—A night view of Buckingham Palace floodlighted by 188 projectors.

The Palace faces East by North and, therefore, as is shown by fig. 1, is only seen under direct sunshine during the early morning hours. Inspections made at intervals throughout the fore-noon made it evident that the facade as a whole appeared most pleasing when the emphasis of the sunshine was provided by rays falling upon the building from the left side. That this should have proved the case is perhaps not surprising when it is considered that the effect created by such directional lighting (shown by fig. 20) is precisely that invariably depicted by artists renowned for their skill in the production of architectural perspectives. This point will be appreciated by those familiar with the work in this particular field of, for example, Cyril Farey, William Walcot and Sir John Burnett.

For this reason, and in view of the relatively slight projection of the ornamental mouldings and other features of the elevation upon which it was desired to obtain the maximum play of light and shade, it was decided that when floodlighting, the beams of light from the projectors should be directed as far as possible upon the face of the building from the left hand side, although it was

obviously impossible to reproduce, as regards direction, the effect of sunlight from above.

The placing of the projectors in the Court Yard, the distance between the projectors and the face of the building measured along the ground in the direction in which the beams from the double row of projectors were trained, and the forward and upward inclination of the beams from the units comprising the main bank are shown respectively by figs. 21, 22 and 23. The appearance of the units viewed from within the Courtyard and the fact that in the position selected they failed to constitute any material obstruction is shown by the photographs reproduced in figs. 24 and 25.

Fig. 20.—The facade of Buckingham Palace appears most pleasing when the rays of sunshine fall upon it from the left side.

From the plan shown in fig. 21, it will be seen that the 188 projectors used were divided into four main groups or sections. Those on either side and at right angles to the front face, are used for the illumination of the two end walls. Along the left hand curve and the left hand portion of the front is shown the main group, the beams from which were directed at an angle upon the main frontage. On the right hand curve will be seen a small group of five projectors, the light from which was also directed upon the main frontage but, as is shown by the arrow, in a direction opposite to that of the main group. The purpose of these may be somewhat obscure. It will be noticed that the main group of projectors did not extend beyond the centre of the building. Consideration will show that the illumination of the facade was produced not only by the concentrated beams from the projectors, but also by the direct (*i.e.*, the unreflected and therefore uncontrolled) light from the lamps, which contributed in particular to the "evening-up" of the surface brightness. In the case of the right hand portion whilst the projected light accomplished quite effectively all that was required of it, the distance from the projectors gradually increased to such an extent that the effect of the uncontrolled light became less and less, and indeed at the extreme right hand edge was practically negligible. To compensate for this gradual reduction in the total light flux reaching this portion of the surface, five projectors fitted with special diffusing front glasses of stippled glass, whose beams had a considerably wider angular spread, were used. Had this correction not been made, there would have been a noticeable falling off on this portion of the frontage, but the use of the type of projector described resulted in the whole of the surface appearing equally bright.

The totally enclosed, long range, narrow angle projectors used were of a type shown in fig. 26. The body consists of a heavy gauge sheet gunmetal drum to which are attached the cast aluminium

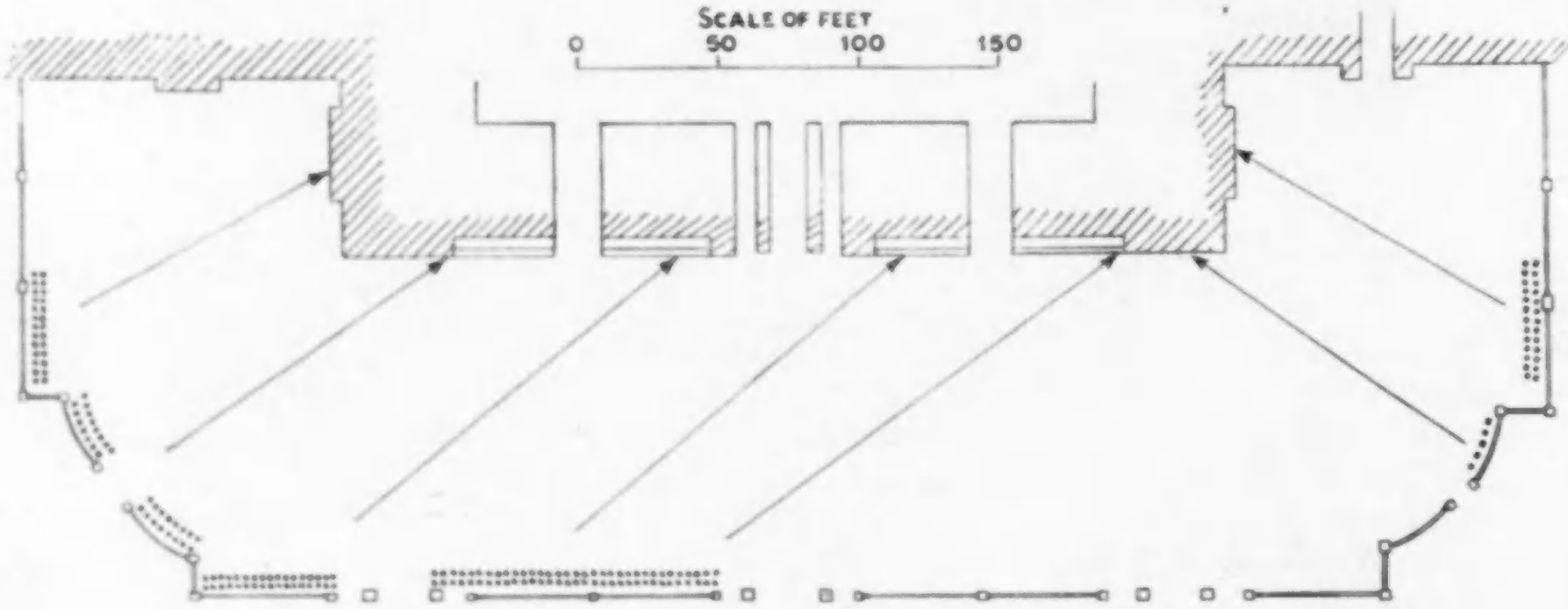


Fig. 21.—Plan of courtyard of Buckingham Palace, showing arrangement of floodlights.

alloy front and the housing containing the focussing mechanism. The supporting cradle is of wrought iron of rectangular cross section, and the circular base of cast iron. Universal movement is provided so that the beam can be trained in any desired direction. The heavy heat-resisting domed front

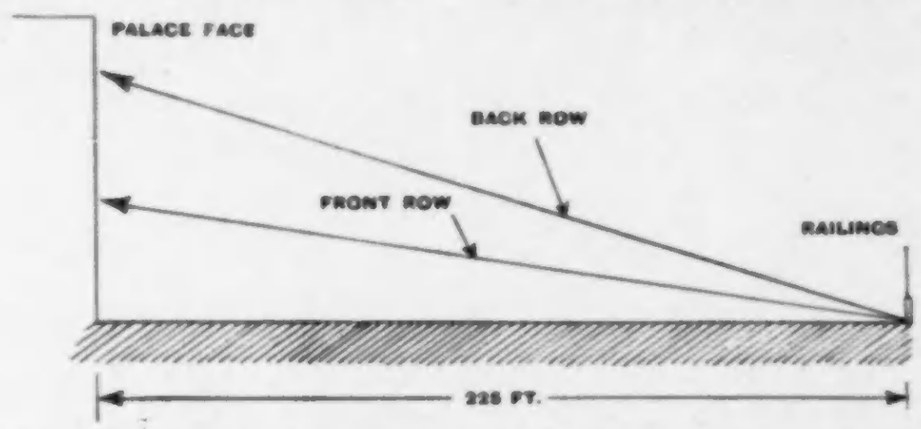


Fig. 22.—Diagram showing length of throw and height of centre of beams on face of Buckingham Palace.

glass is carried by a hinged front ring which is secured in position by wing nuts. A feature of the construction which is specially valuable in an installation involving the accurate training and setting of a large number of projectors, is the strong and durable mistake-proof "pre-set" device which is provided. The advantage of this lies in the fact that once the responsible engineer has completed his adjustments and securely locked in position the pre-setting mechanism, the projectors can be moved into any position convenient for cleaning or replacing lamps, with the certainty that, when returned to the position determined by the stops on the "pre-set," both the direction of the beam and the angle at which it is inclined will be exactly in accordance with the original setting. The importance of this point is too obvious to call for further comment.

The single piece reflector is of Gecoray silvered glass, which is constructed of crystal glass backed with silver, over which is deposited one or more coatings of copper, the whole being protected by a weather resisting lead backing, with the result that the reflector is practically indestructible under normal conditions of use. The silvering conforms to the Admiralty Specification for searchlight mirrors, and the reflectors have the highest reflecting factor of any reflecting surface commercially practicable for use in floodlights.

The overall dimensions of the projector are shown by the drawing reproduced in fig. 27, which also makes clear the fact that the construction of the supporting cradle enables the body of the projector to be completely reversed within the supporting arms, so that the focussing mechanism can be either at the top or the bottom. This feature is of considerable practical value in as much as it enables either a standard general service gasfilled lamp (which, if maximum burning life is desired *should*

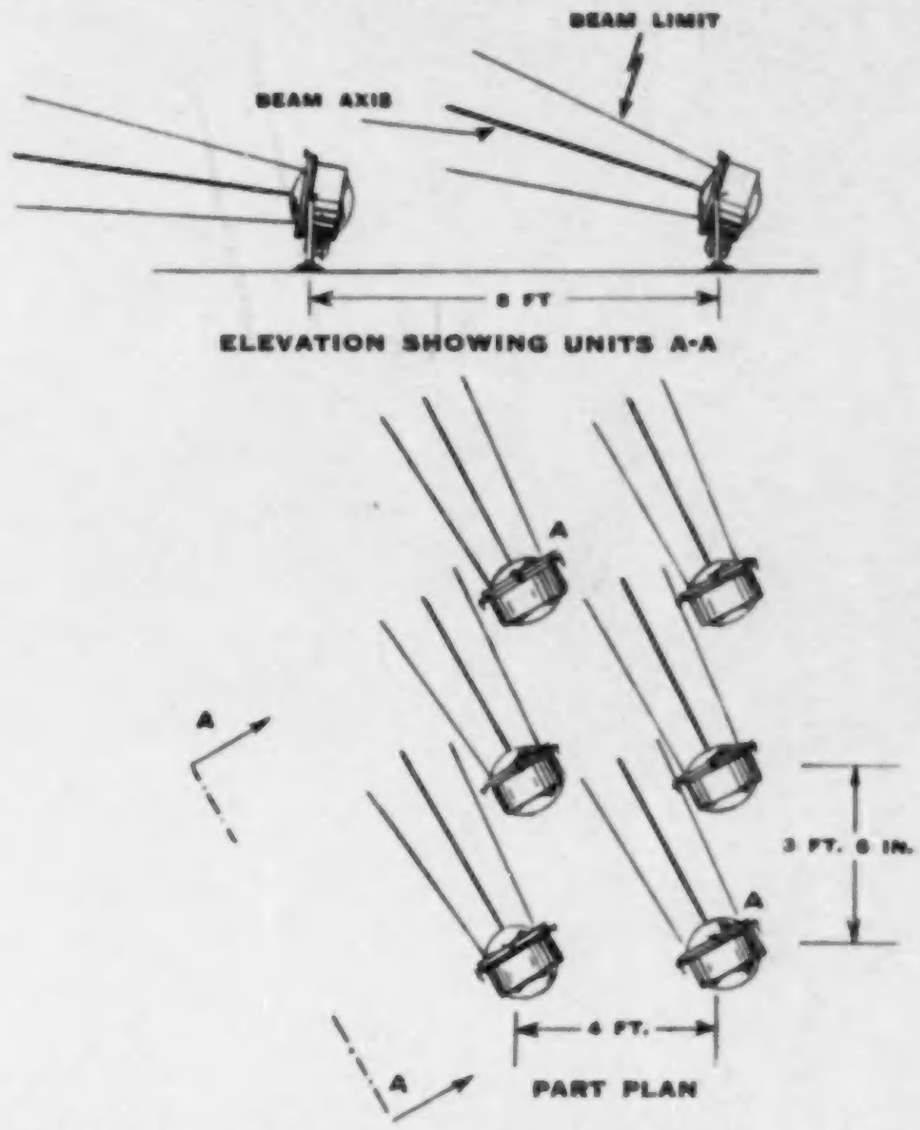


Fig. 23.—Part plan and elevation showing forward and upward inclination of projectors.

always be used cap upwards), or a projector type round bulb gasfilled lamp (which *must* always be used cap downwards) to be utilised in the one projector. This is effected, when it is required to use the projector lamp, by the addition of a simple distance piece to raise the position of the lamp

73664

Fig. 24.—Interior of courtyard showing location and arrangement of side groups of projectors.

holder. The correct position within the projector of each type of lamp is shown on the drawing.

When used in conjunction with a 200 volt 1000 watt Class B Osram gasfilled projector lamp, of the round bulb floodlighting type (as

Fig. 25.—Interior of courtyard showing main group of projectors.

employed in the Buckingham Palace installation) and focussed for maximum concentration, the resultant beam possesses the characteristics shown by the curve reproduced in fig. 28, the angular divergence being ± 6° (commercially a 12° beam) and the maximum intensity 340,000 candles.

The projector is fitted with a front of heat resisting glass which is normally of clear glass. Alternatively, a diffusing spreader, or spreader deflector front glass of one of the types illustrated in figs. 29, 30 and 31 may be used.

Stippled front glasses, also known as diffusing glasses, fig. 29, give diffused beams with materially reduced peak intensities and consequently softer shadows.

Spreader front glasses, fig. 30, have similar properties, but do not act equally in all directions. Their effect is to widen the beam into an oval and they are particularly useful where a broad band of light is required. The band can be horizontal, vertical, or at any angle in between according to the setting of the glass in the projector.

Spreader-deflector front glasses, fig. 31, have a similar widening effect in one direction with a simultaneous slight deflection of a portion of the beam towards the axis, a feature which is often of value in the floodlighting of buildings where it is desired to prevent the projected light from extending over the top or beyond the side edges. Front glasses of this type are also extensively used for the floodlighting of aerodromes and landing grounds where it is essential to prevent the rays of light rising materially above ground level ; they are therefore also known as air port spreader glasses.

The influence of the front glass upon the beam of light emitted by the projector is shown by the curves in fig. 32. As will be seen, the effect of the clear front glass produces a slight reduction in the maximum intensity of the beam without material alteration in its shape. Diffusing glasses, which are normally of stippled glass, as shown in fig. 29, not only reduce the maximum beam intensity but also spread the light over a wider angle. The lamp, of course, still gives exactly the same light output, but, apart from a certain amount of absorption, the spread is so greatly increased that the change in the *shape* of the curve is quite pronounced. The great practical advantage obtained by the use of such glasses is that, as already indicated, due to the increased diffusion of the light, shadows such as those cast by mouldings or decorative features on the face of a building, are not only very much softer but are less sharply defined and in certain circumstances very much more pleasing. Such glasses are also of value in the elimination of filament

Fig. 26.—General view of unit used for the floodlighting of Buckingham Palace.

striation, to which further reference will be made later. Spreader glasses and spreader-deflector glasses, which are usually of the prismatic type illustrated in figs. 30 and 31, spread the light in the form of a broad band to such an extent that the characteristic

shape of the beam practically disappears. The maximum intensity is, as indicated by fig. 31, of substantially the same order as that resulting from

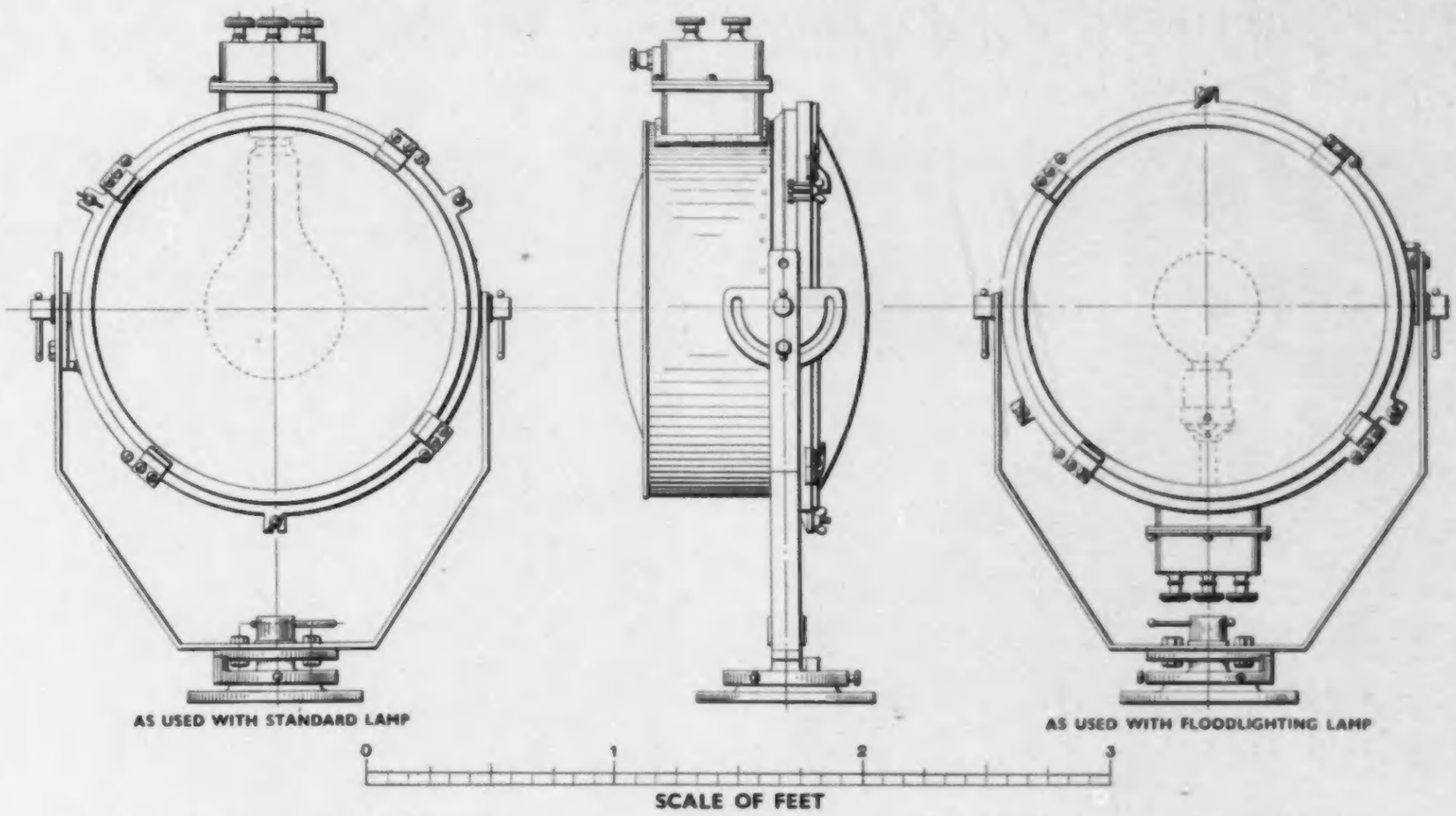


Fig. 27.—Arrangement drawing of floodlight used in the Buckingham Palace installation.

Fig. 28.—Beam intensity curve for 1000 watt Gecoray floodlight reflector.

the use of the stippled diffusing glass. The curve shows higher intensities than those given by the unit when fitted with the stippled diffusing glass at angles greater than about four degrees from the centre, and it might therefore be thought that the spreader glass was the more efficient. It must be remembered that whilst the beam from the projector fitted with the stippled diffusing glass is of circular cross section and the curve indicating its performance therefore represents a solid of revolution the plan of which is a circle, the light emission of the unit when fitted with the spreader

Fig. 29.—Stippled diffusing front glass.

glass is shown by the curve in a horizontal direction only, the light in this case being in the form of a band, *i.e.*, the circle is elongated and becomes a broad band. Actually, comparison of the total beam lumens in each case shows a slight advantage in favour of the stippled glass.

In the Buckingham Palace installation all the projectors were fitted with clear glass fronts with the exception of the small group of five located on the right hand side, as shown in fig. 21, to which we have previously referred as being used for the evening-up of the illumination of the front. These were fitted with stippled glass diffusing fronts not only for the securing of a wider beam spread but also in order that the strong shadows caused by the highly directional angular light rays from the main group of projectors striking the decorative and ornamental features on the face of the building should neither be obliterated nor off-set by equally pronounced and equally directional shadows in the reverse direction, which, had they been present, would have entirely spoiled the appearance of the facade as a whole.

Fig. 30.—Prismatic spreading front glass.

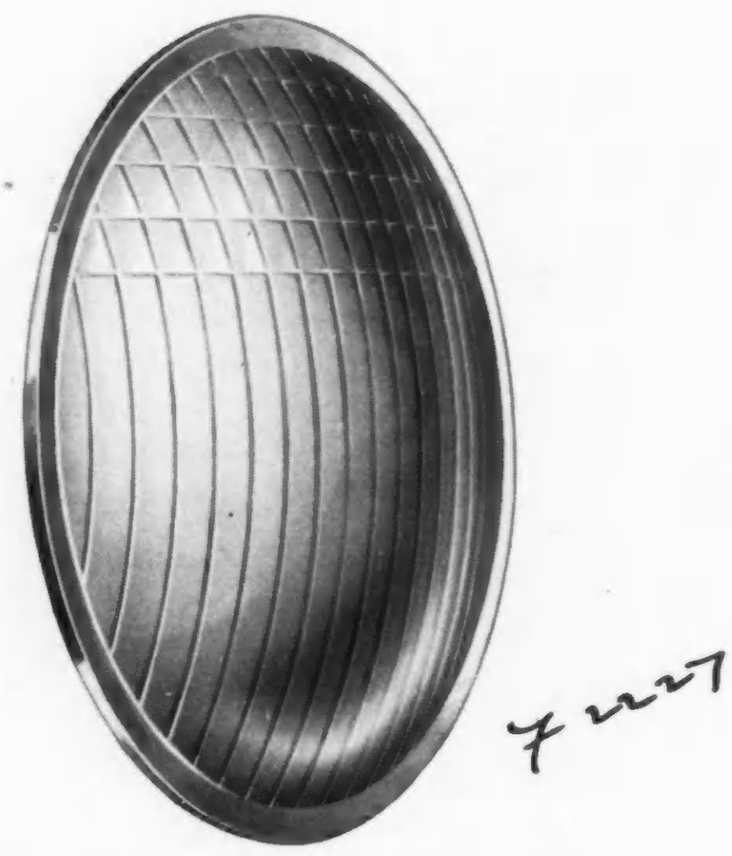


Fig. 31.—Airport spreading front glass.

By reference to figs. 19 and 20 it will be seen that the main frontage of the Palace is very cleverly broken up both by the skilful application of the correct principles of fenestration and by the employment of the numerous fluted pillars and pilasters, corinthian caps and moulded bases, pediments, balustrades and enrichments generally which are clearly shown. For this reason such striations as resulted from the use of the clear glass fronts were virtually invisible and could safely be ignored. Had the facade presented the appearance of a flat and unbroken white, or really light coloured surface, the filament striation would have proved objectionable and it would probably have been necessary to equip the whole of the projectors with stippled diffusing front glasses and to increase their number to an extent sufficient to overcome the loss of light resulting from the absorption of these glasses.

In fig. 33 are reproduced two photographs showing the illuminated field produced by directing the beam of light from a floodlighting projector, equipped with an Osram 500 watt general service zig-zag filament lamp, on to the surface of a white linen lantern screen, 10 feet from the projector, and photographing the resultant illuminated field. At the time the left hand photograph was taken the projector was fitted with a clear front glass. The right hand photograph shows the alteration in the appearance of the screen which resulted

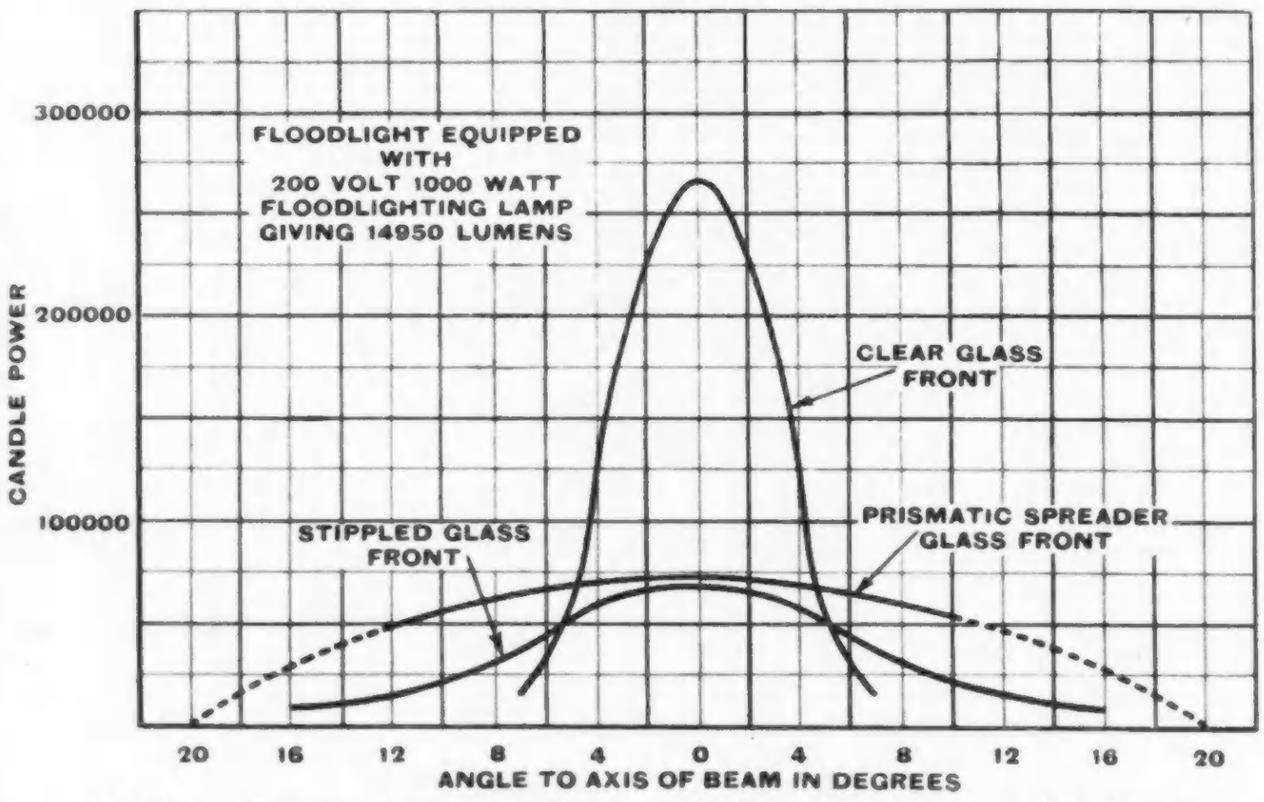

300000
200000
100000
CANDLE POWER
FLOODLIGHT EQUIPPED WITH 200 VOLT 1000 WATT FLOODLIGHTING LAMP GIVING 14950 LUMENS
CLEAR GLASS FRONT
PRISMATIC SPREADER GLASS FRONT
STIPPLED GLASS FRONT
20 16 12 8 4 0 4 8 12 16 20
ANGLE TO AXIS OF BEAM IN DEGREES

Fig. 32.—Curves showing influence of diffusing and spreading front glasses on both the shape and max. intensity of the beam.

from the use of a diffusing stipple front glass, all other conditions remaining unchanged. In the left-hand illustration some few of the whirls of the filament image, increased many times in number by the effect of the mirror reflector, are clearly visible. The disturbing effect of such striations, magnified many times on a plain white surface, as would be the case in practice, can more readily be imagined than described. In the right hand illustration not only has the diameter of the illuminated field been increased, owing to the more extensive beam dispersion, but the striation has been almost entirely eliminated. The maximum intensity is, it is true, reduced to some extent but it is evident that the resultant illumination is much more even. It may be explained here that the vertical and horizontal markings which are faintly visible on the right hand illustration, are actually the threads in the linen lantern screen, which under the intense illumination applied presented the appearance shown.

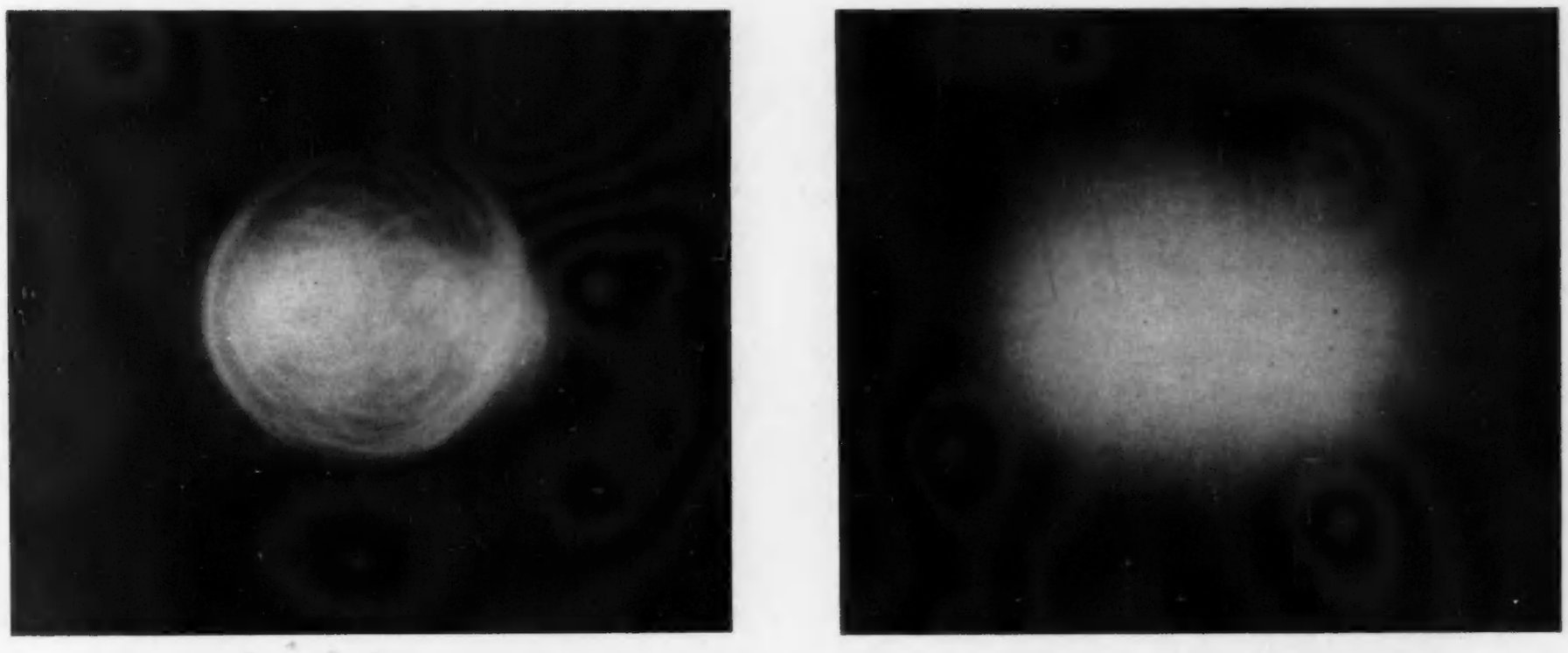


Fig. 33.—Illustrations showing effect of stippled front glass in eliminating filament striation.

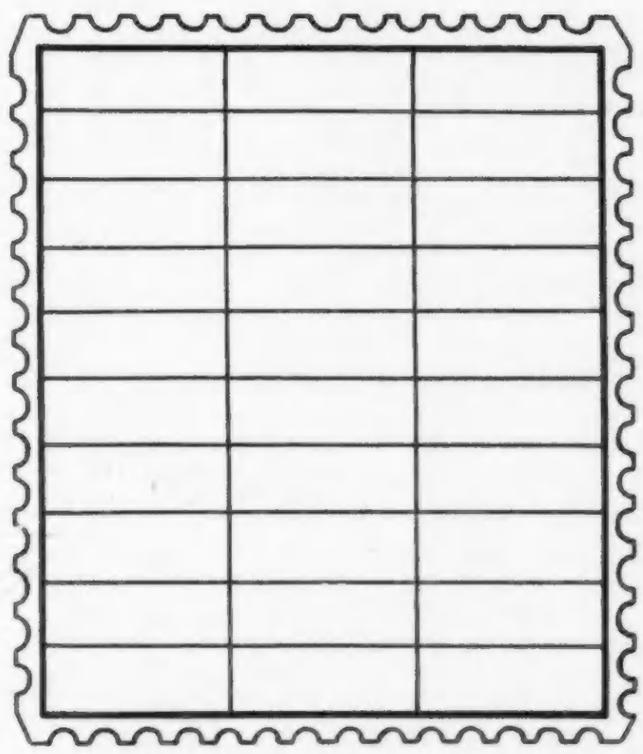


Fig. 34.—Representation of postage stamp twice full size divided into 30 equal areas for testing purposes.

As soon as the installation at Buckingham Palace was completed there was widespread speculation as to the actual intensity over the facade, and many enquiries were made for imformation upon this point. Those who were interested in the technical side were anxious to know, in addition, the order of agreement between the predicted value and that which was finally obtained. Obviously the second question could not be dealt with until the answer to the first was not only known, but known with sufficient exactitude to enable a reasonable approximation of the true *average* to be determined.

The ascertainment, by the making of photometric measurements, of the average intensity over a high vertical surface of large area is by no means as easy as might be supposed. The actual photometric measurements do not in themselves present any difficulty to those experienced in such work. The trouble lies in the difficulty of access to a sufficiently large number of representative portions of the illuminated surface to give a reasonably true and accurate average value. It must be remembered that, since much of the light falling upon the surface to be measured is coming from sources *behind* the observer, it is practically impossible for him to prevent the cutting off of a certain amount of light by himself and his apparatus. This must be avoided if the resultant determination is to be of any real value. The question to be solved was how could this essential immunity from the interference of even the faintest shadows be secured?

As this problem had been encountered on previous occasions, considerable investigation had been made into the subject at the G.E.C. Research Laboratories. This resulted in the invention and development of an entirely new form of photometer

which completely overcame not only this difficulty but also many others. Briefly, it may be described as a combination in a single instrument of the properties of a telescope and a photometer which measures the brightness of a surface illuminated by either natural or artificial light from a considerable distance. Having made such measurements it is only necessary to ascertain the co-efficient of reflection of the material of which the surface is composed to enable the results to be translated into foot-candle intensities. One of the most important of the many practical advantages possessed by this unique instrument is the fact that the accuracy of its adjustments is such that, even from a view point located at so considerable a distance from the surface under consideration as to eliminate the possibility of the cutting off of light or the casting of shadows, it is possible to make a large number of individual measurements over a surprisingly small space. In fig. 34 is reproduced to a scale of twice full size, a representation of a postage stamp of exactly the same size as an ordinary English penny stamp. During a demonstration of the new instrument, which is known as a telephotometer, the inventor actually made (and the author checked) no less than thirty separate and distinct measurements over the surface of the postage stamp located at a distance of ten feet from the instrument. This means that the surface brightness of each of the thirty spaces bounded by the black lines shown on the illustration was separately measured. It is not suggested that measurements at so close a spacing would, or need ever be made in practice, but as demonstrating the capabilities of the instrument the experiment was conclusive.

The Buckingham Palace installation offered a most appropriate subject for the first commercial use of the new instrument. The necessary measurements were duly made and the iso-foot-candle diagram shown in fig. 35 was ultimately produced. This, the first of the kind to be produced by this means, shows the distribution of the illumination on the surface of the facade and enables all manner of interesting determinations to be made. One can, for instance, ascertain the true average illumination over the whole of the surface, the location and value of both the maximum and the minimum illumination, and the extent to which the intensity varies over the face of the building. Actually, the average intensity was found to be 14.7 foot-candles, the maximum 45 foot-candles, the minimum 5 foot-candles, and the inequality ratio nine to one. The disposition over the face of the building of the areas enclosed by the contour lines representing various illumination values, which should be studied in conjunction with the lay-out plan reproduced in fig. 21, is both interesting and instructive, and the information thus obtained should prove of considerable value to those contemplating similar installations.

The second question, namely, the difference between the results predicted and those actually obtained, can be disposed of very shortly. Of the several preliminary schemes arrived at by calculation (no actual tests being possible for the reasons already given) that finally selected was designed to secure an average intensity of from 15 to 18 foot-candles.

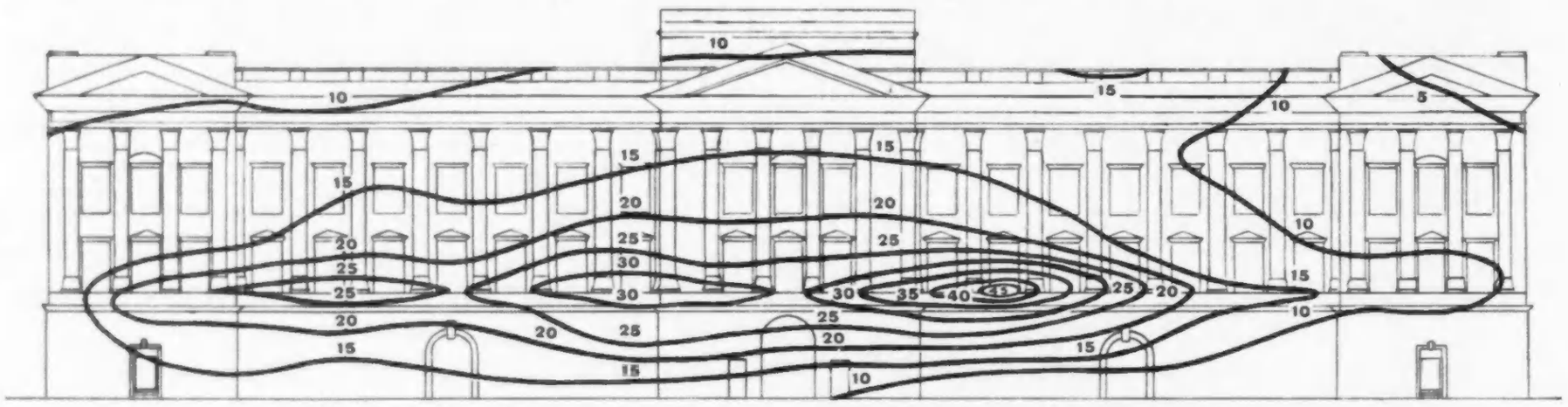


Fig. 35.—Iso-foot-candle diagram of facade of Buckingham Palace.

As the installation was only intended to be in operation for a few weeks, no allowance was made for depreciation.

The photometric tests were made after the equipment had been used each night for several weeks, during which time some slight depreciation must undoubtedly have taken place, and the order of agreement between the forecast and the realization may, therefore, be looked upon as highly satisfactory.

A feature of especial interest to illuminating engineers was the fact that, although the inequality ratio was actually 9 : 1, the whole of the surface appeared from a visual point of view to be evenly illuminated.

Before leaving the subject of the Buckingham Palace installation and proceeding to the consideration of others of a different character, reference should be made to the influence upon the appearance of a floodlighted exterior of the presence or absence of a sufficient amount of contrast in the subject itself. Many observers were of the opinion that, under the floodlighting, the appearance of the facade of the Palace was too flat and reached the erroneous conclusion that the supposed flatness was attributable either to the use of too high an intensity or to the illumination being too even. In reality the question

was a matter of contrast. The average intensity, although probably the highest which had been seen in this country up to that time, was actually less than that commonly used in certain of the successful American examples, such as, for instance, the floodlighting of the White House, which, considered as a surface, is actually lighter in colour than Buckingham Palace. As the intensity varied from 5 to 45 foot candles, as is shown in fig. 35, the illumination was obviously not too even. The apparent defect was due to the fact that throughout the period during which the floodlighting was in operation the blinds

Fig. 36 (a).—The floodlighting of Buckingham Palace as it actually appeared with the blinds drawn.

Fig. 36 (b).—As Buckingham Palace would have appeared when floodlighted, had the blinds been raised.

of Buckingham Palace were drawn during both day and night. It also happened that the colour of the buff blinds almost exactly matched that of the stone with which the front is faced. The result was an almost entire absence of colour contrast, producing the apparent flat appearance seen in fig. 19. That this was so, and that the flat effect was not in any sense the result of the floodlighting will be apparent from a careful comparison of figs. 19 and 20.

Such comparison renders evident the fact that every particle of relief was as clearly revealed by

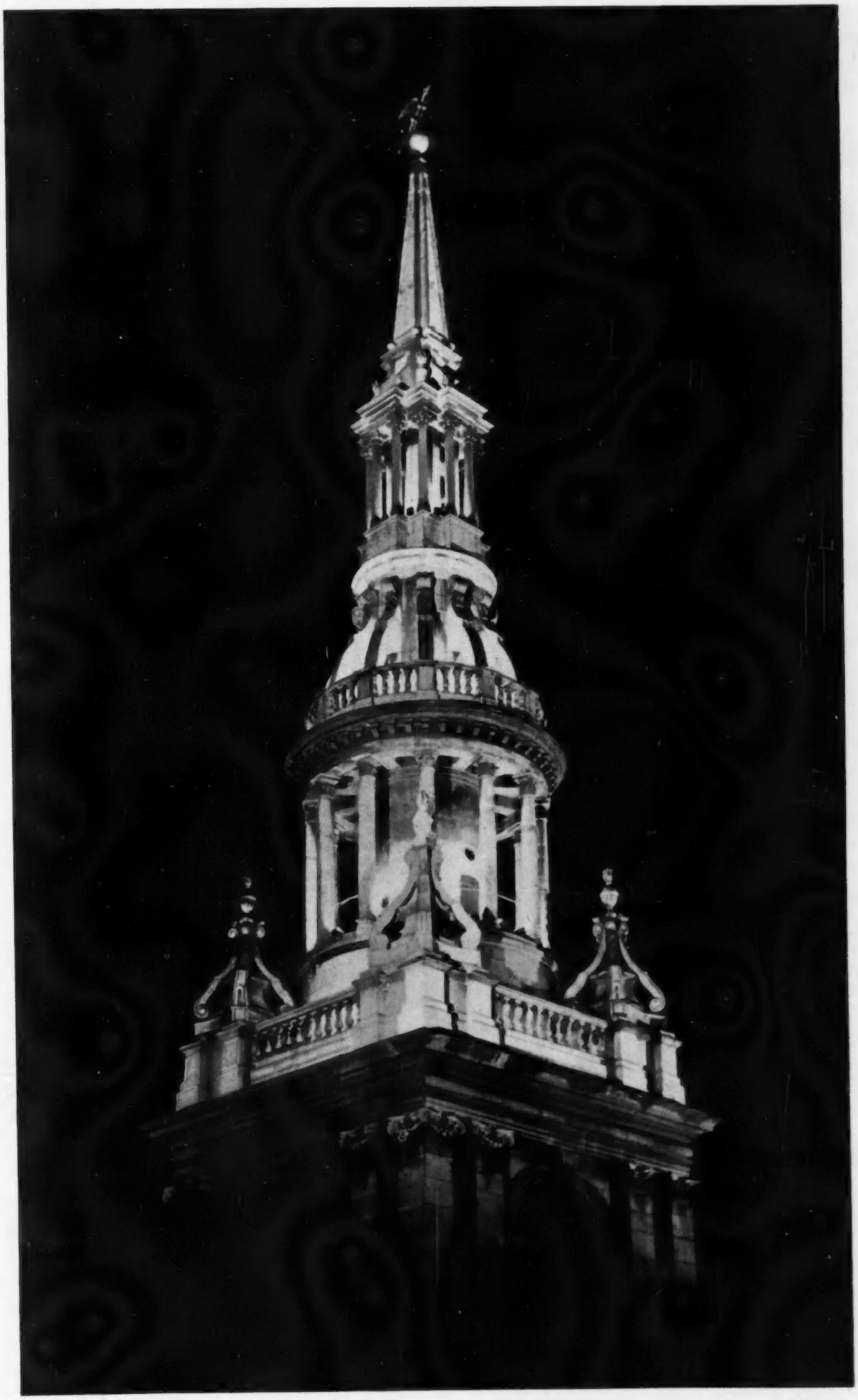
Fig. 37.—Floodlighting of the Victoria memorial.

night under the artificial lighting as by day under the natural sunshine. In each case the columns appeared round; the flutings on both the columns and the pilasters quite definitely appeared as depressions; the mouldings stood out in excellent relief and could never have been mistaken for anything other than mouldings; even the patterning of the window bars was clearly shown.

It is therefore apparent that the flat appearance was not due to the absence of sufficient light and shade, but to the almost total lack of colour contrast. For the purpose of establishing this fact the photographs shown in figs. 36 (a) and (b) were obtained. The only difference between them is that the upper illustration shows the appearance which was in fact presented when the blinds were drawn, and the lower that which would have been presented had it been possible to have arranged for them to have been raised during the floodlighting, or alternatively, had they happened to have been of a colour such as dark blue, a colour which would have provided a good contrast with the buff stonework. The lower picture not only shows that the contrast provided is ample but is full of life and vigour. In the absence of a demonstration so convincing as that provided by these photographs, it is difficult to realize that so effective an improvement could have been effected in so simple a manner.

The floodlighting of the Victoria Memorial was of special interest from a very unusual point of view. During the Congress the floodlighting of both the Palace and the Memorial was simultaneous. For this reason, and also because the Memorial was normally viewed against the facade of the Palace—which it will be remembered, was illuminated by white light—it was necessary, without resorting to the use of a strong colour, deliberately to create between the two subjects a colour contrast which was sufficiently pronounced to ensure that the one would stand out prominently against the background of the other. The Memorial, which is of white marble, was therefore illuminated by light of a golden amber tint. Its appearance during the floodlighting is shown by the photograph reproduced in fig. 37, which affords an excellent representation of the dignified and beautiful spectacle which it presented. At the time at which the photograph was taken the floodlighting of the Palace was switched off for a reason which will later become apparent.

Had an artist been given the task of painting a picture of the Memorial in an amber tint, he would undoubtedly have set out to retain the appearance of a third dimension and the impression of the "roundness" which actually existed by making use of tints of various shades. He would also have emphasized the high lights on the subject in the customary manner by the addition of sundry touches of pure white. The problem set by the responsible officials was that of obtaining from the floodlighting precisely such an effect. In other words, the illuminating engineers were asked to paint by means of light alone such a picture as the artist would have produced by the use of a complete range of amber colours plus the use of white for the high lights. The solution was reached by making a selection of amber screens of varying tints. The floodlights, which were all of the same size and were all equipped with lamps of the same type and wattage, were located behind the vertical marble surround which



7 3403

Fig. 38.—Floodlighting of the steeple of Bow Church, London.

is visible in the illustration and were therefore arranged in a circle. Only a single row was used. At a point opposite the centre of each of the four sides of the square upper portion, a single projector

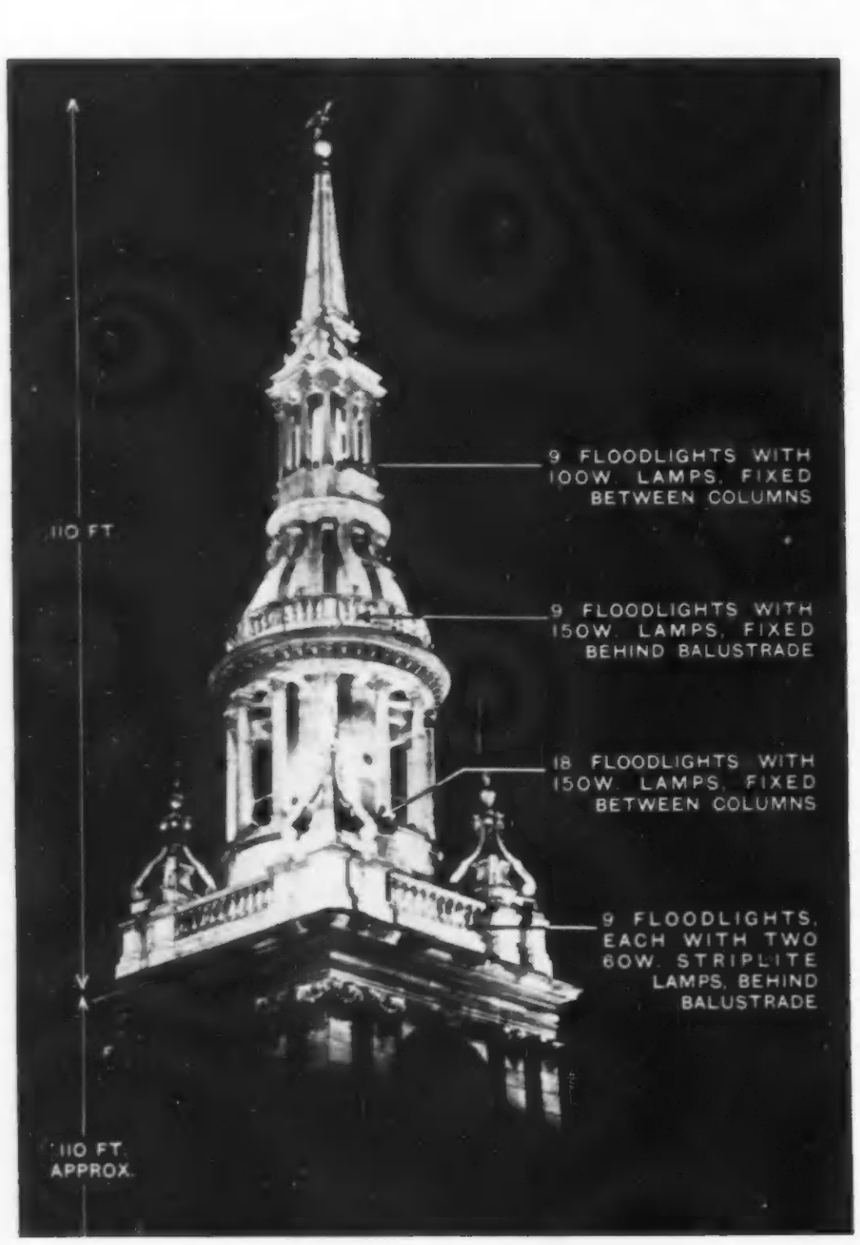

110 FT.
9 FLOODLIGHTS WITH 100W. LAMPS, FIXED BETWEEN COLUMNS
9 FLOODLIGHTS WITH 150W. LAMPS, FIXED BEHIND BALUSTRADE
18 FLOODLIGHTS WITH 150W. LAMPS, FIXED BETWEEN COLUMNS
9 FLOODLIGHTS, EACH WITH TWO 60W. STRIPLITE LAMPS, BEHIND BALUSTRADE
110 FT. APPROX.

Fig. 39.—Key illustration of steeple of Bow Church.

was used without any screen, *i.e.*, giving uncoloured light. On either side of this the adjacent projectors were equipped with amber screens of a light tint. On the next, on either side, screens of a deep tint were employed, and so on until, at the positions corresponding to the four corners of the square, the screens used were of the deepest amber. The gradation of tone and depth of colour on the surface of the Memorial which were obtained were clearly visible even when the former was viewed against the bright background presented by the illuminated Palace, but as it was particularly desired that this effect should, if possible, be visible in the illustration reproduced in fig. 37, it was considered expedient, owing to the limitations of the photographic plate, to switch off the lighting of the Palace during the exposure, and thus increase the likelihood of rendering visible in the reproduction the effect which it was desired to portray.

In discussing the floodlighting of Thames House, illustrated in fig. 14, reference was made to the almost unlimited scope afforded to the illuminating engineer by the skilful combination of an appropriate scheme of general lighting with, superimposed upon it, an individual and sectional scheme of local lighting designed specially for each building.

An equally interesting and, in the opinion of many perhaps even more beautiful example of the effectiveness of such treatment, was furnished by the floodlighting of the Church of St. Mary-le-Bow, which is shown by the photograph reproduced in fig. 38.

This church, one of the most interesting and world famous examples of the work in the English Renaissance style of Sir Christopher Wren, is beloved of Londoners the world over, as the home of the celebrated Bow Bells and by reason of its association with the story of Dick Whittington. At the time of the Congress the Church was, and is still, undergoing reconstruction, and an appeal had been issued for funds to defray the cost of the restoration. It was in part for the furtherance of this appeal that the floodlighting was carried out.

The equipment providing the general illumination was located on the roof of buildings on the opposite side of Cheapside, in the positions indicated on the plan shown in fig. 40. Eight projectors were used in all, four in each position.

Superimposed upon the general lighting thus provided, was that produced by the use of the four additional banks of projectors fixed at the ascending levels indicated on the key photograph reproduced in fig. 39, and, in plan, arranged in the manner shown by fig. 41. The data given upon the key photograph and the series of small plans, is so complete that its further elaboration is unnecessary. The total load was 14,030 watts.

The floodlighting was very carefully co-ordinated with the architecture so as to emphasise, by the lighting, the architectural beauty of the structure as a whole. The arrangement of the lighting units

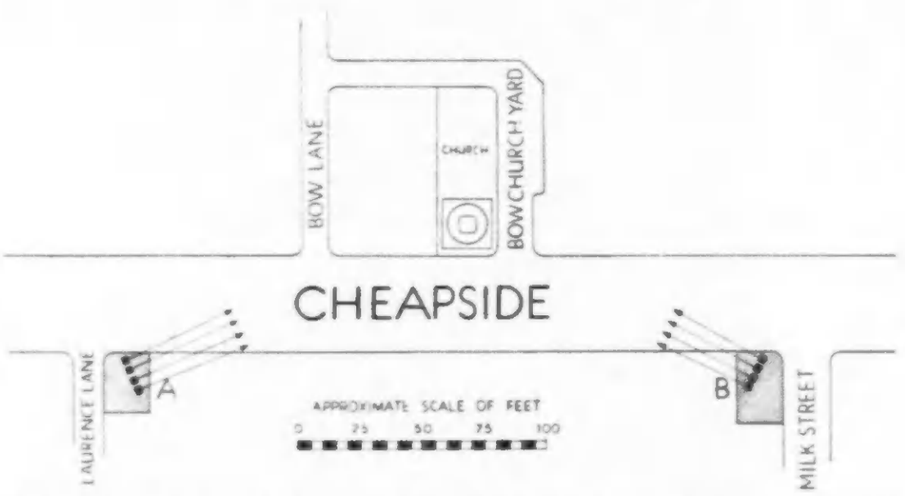


Fig. 40.—Plan of Cheapside showing location of floodlights illuminating Bow Church.

in what were, from the observers point of view, tantamount to concealed recesses, gave relief and depth to the architectural detail, without in any way appearing to weaken the structural lines of the building.

Had the floodlighting been confined to the illumination of the exterior of the steeple by the

projectors used for the provision of the general lighting, the result would have been very much less satisfactory, because, although a sufficiently high intensity could quite easily have been provided in this way, the heavy and unsightly shadows which would then have been cast by the various balconies, balustrades and columns would have completely ruined the effect.

Somewhat similar in character although differing in certain essential details of its treatment, the floodlighting of the new Beffroi, which surmounts the Hotel de Ville at Lille, constitutes yet another interesting example of dual treatment.

The tower, fig. 42, which rises to a height of approximately 350 feet, possesses considerable architectural charm and is one of the most imposing structures in the whole of France. Handsome as is its appearance by day, its appeal during the hours of darkness when illuminated by a battery of 70 floodlights is strikingly arresting. It is generally considered one of the most successful permanent installations of floodlighting yet achieved.

Referring briefly to the details of the tower installation, the base is illuminated by two projectors, each equipped with a 1,500 watt general service lamp. On the first balcony which is confined to the front, one similar projector is used with a similar 1,000 watt lamp. On each of the angular balconies on the second balcony are installed three projectors, two of which are equipped with 1000 watt general service lamps and one with a floodlighting lamp of similar wattage, together with one projector using a 1,500 watt general service lamp. On each of the front balconies, four projectors are provided, two of which are fitted with 1000 watt general service lamps and two with floodlighting lamps of similar wattage. The portion of the tower immediately beneath the two upper balconies and the lantern house are brightly illuminated internally for the purpose of creating the beautiful silhouette effect shown by the illustration, an effect to which is attributable no small measure of the success of the installation as a whole. On the lower of the two circular balconies are used four projectors with 1000 watt general service lamps (this projector is now arranged to take only 1000 watt floodlighting lamps) and twelve projectors with 500 watt floodlighting lamps. On the topmost circular balcony are located eight projectors each with a 500 watt floodlighting lamp, and in the lantern house at the top, a further eight projectors, each with a 200 watt general service lamp. The main frontage of the building, right and left of the tower, is also effectively floodlighted and the main entrance lighted indirectly, but as these portions of the installation represent perfectly normal practice it is unnecessary to refer to them in detail.

Considerations of space make it impossible to discuss the further aspects of floodlighting, but it must be pointed out that the floodlighting of pageants and open air plays, of parks and gardens, of spaces devoted to such open air games and sports as football,

Fig. 41.—Plan showing location and arrangement of floodlights at different levels on steeple of Bow Church.

golf, tennis, bowling, hockey, curling and skating, are subjects of great interest to the lighting engineer. The floodlighting of bathing beaches and the illumination by under-water floodlighting of both outdoor and indoor swimming baths present an entirely

different and equally interesting set of problems. These, together with such subjects as the floodlighting of railway goods yards, docks and wharves have necessarily remained untreated. The subject of colour floodlighting, and, in particular, of colour floodlighting by the utilisation of the new hot cathode floodlighting lamps is of such importance that it is proposed to make it the basis of a future article.

In conclusion the author desires to acknowledge his indebtedness to all those to whom acknowledgment is due, and, in particular, to thank Sir Frank Baines, Mr. Percy Good, Mr. J. Aimes and Mr. W. J. Henley for their inspiration and assistance.

Fig. 42.—Floodlighting of the Beffroi de Lille.

A New Construction for Receiving Valves

(MANUFACTURED UNDER THE REGISTERED TRADE MARK "CATKIN.")

By C. J. SMITHELLS, and D. A. RANKIN

(Communication from the M.O. Valve Co., Ltd.)

In this article the authors describe the construction of a new range of valves, made by the M.O. Valve Company Limited, an Associate of The General Electric Company Limited, under their trade-mark "Catkin." The new valve works on exactly the same principles as the ordinary thermionic valve but involves a complete revolution in construction.

The design is based solely upon the requirements of the valve itself and the soundest engineering principles by which these could be achieved.

THE evidence of a thermionic current being drawn from a hot filament was obtained by Edison as early as 1883. The true nature of the current was not established until 1899, when J. J. Thomson showed that it was due to electrons leaving the filament. The first practical application of this to wireless was made by Fleming in 1904. His earliest valve was in effect a carbon filament lamp with the addition of an aluminium anode. The next step was the addition of a control grid by De Forest, which converted Fleming's rectifying valve into an amplifier. Commercial development was very slow until the War, when it received a great impetus as the result of military requirements. The only people who had the necessary plant and technique at their disposal were lamp manufacturers, with the result that the valve tended to develop entirely along the lines of lamp construction.

Actually the only feature common to lamps and valves is an electrically heated filament operated in a vacuum. Here the similarity ends, for their functions are entirely different, and the lamp form of construction continued to survive mainly because of tradition. Improvements in radio receiving sets which have been taking place in recent years have emphasised certain weaknesses in the receiving valves they employ. These new sets call for a much greater uniformity in characteristics from one valve to another of the same type, combined with higher efficiency, necessitating closer clearances between the electrodes and greater accuracy in maintaining them. Microphonic and other noises in the valve can also be tolerated to a less degree than in the past. Then the introduction of midget sets and car sets, and the use of a much larger number of valves as in superheterodyne sets have brought a demand for valves of the smallest possible size.

When these demands are borne in mind it is evident that the conventional, or "lamp" design of valve is far from ideal. In the first place the glass bulb, which was necessary in the lamp to keep out the air, without keeping in the light, has many drawbacks. The glass envelope makes the dissipation of heat from the anode difficult, so that when the valve is operating this electrode may reach a temperature of 500° C. or more. In consequence it is necessary to out-gas all the electrodes at a still higher temperature during the pumping process, either by electronic bombardment or eddy current heating. Both these processes are expensive, and the materials of the electrodes are limited to those metals of sufficiently high melting point to withstand these temperatures. Finally the glass bulb is both fragile and bulky.

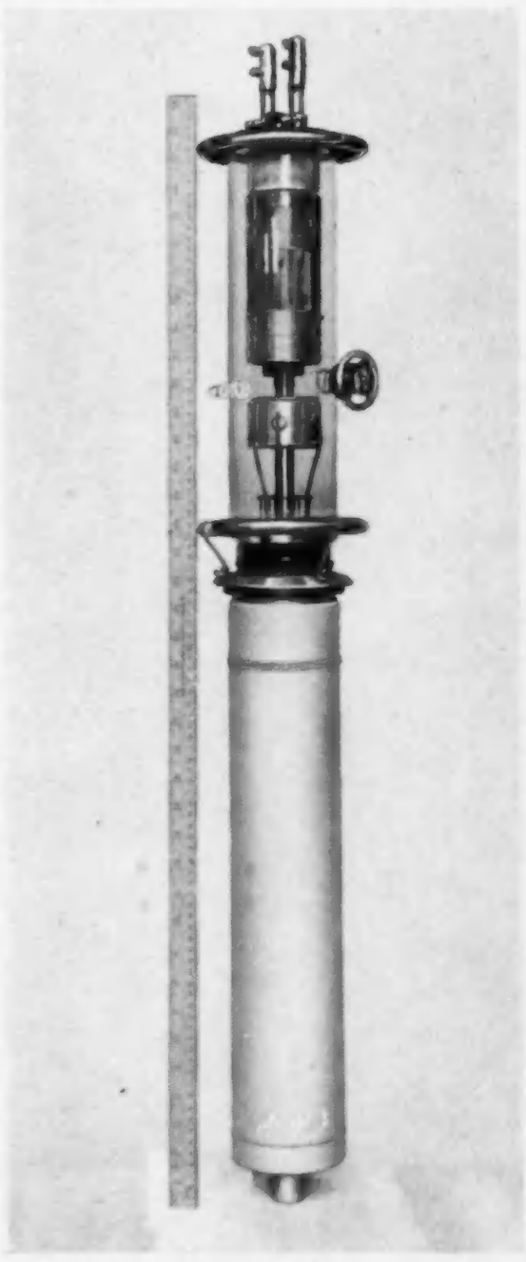


Fig. 1.—100 kW water-cooled transmitting valve.

An alternative construction is to make the metal anode itself form the chief part of the envelope of the valve. This has been done for many years in large transmitting valves (C.A.T. type) but in spite of the success attained with these valves the principle has not previously been extended to their smaller brothers. In transmitting valves many kilowatts of energy have to be dissipated, and the anodes are cooled by a stream of water or oil. One of these valves is shown in fig. 1.

(i) GENERAL PRINCIPLES OF CONSTRUCTION IN THE NEW VALVES.

In "Catkin" valves this form of construction has been adopted; the anode forms the envelope and is air cooled, glass being only used where it is required as an insulator. This is

the most noticeable departure from standard practice in the appearance of the valve. The temperature of the anode varies from 60° to 150° C. in operation according to the type of valve, and consequently

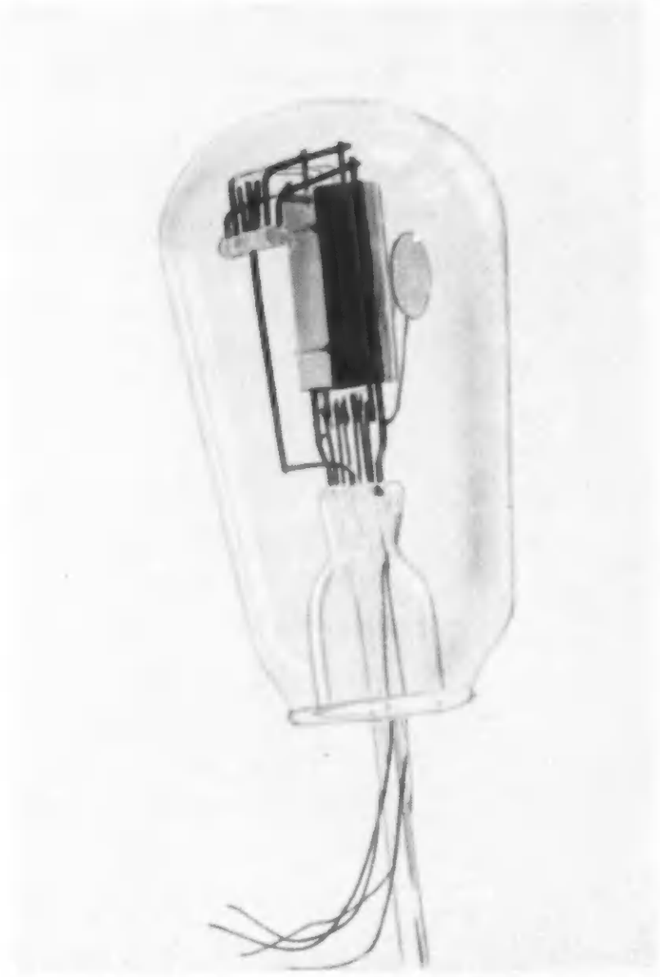


Fig. 2.—Typical construction of glass receiving valve.

it is sufficiently out-gassed by the ordinary baking during pumping. Owing to the small area of glass the valves can be baked at 550° C. without collapsing as compared with 450° C. for glass valves. In consequence of the lower temperature at which the anode runs, the temperature of the grid and other components of the valve is also reduced and these also do not require to be heated to such a high temperature during manufacture.

The lamp form of construction involves the use of the familiar glass pinch to carry the leading-in wires to the electrodes. Fig. 2 shows a typical form of construction used for glass valves until recently. The electrode system is assembled on the pinch by numerous welds, and a certain amount of wire bending is necessary to locate the electrodes in their correct positions. Not only is it difficult to attain uniformity from valve to valve by this method of construction, but the whole electrode system mounted in the centre of a bulb on the end of a relatively slender support is particularly responsive to vibration, causing microphonic noise. This form of construction is also weak from a mechanical point of view, and a severe shock may alter the relative positions of the electrodes and affect the characteristics of the valve, although the latter is not actually broken.

In "Catkin" valves the cathode and grid (or grids) are mounted as a unit in mica spacing pieces which fit accurately inside the anode, so that subsequent movement of the electrodes is impossible. This method of construction eliminates wire bending, and reduces the number of welds to a minimum. The various grid damping wires, and the cathode and heater supports are then rigidly held in a pressed steel and mica clamp.

Finally the envelope is closed by a new form of circular seal, round the circumference of which the leading in wires are spaced. This gives the maximum insulation between the wires and provides an unrestricted exhaust tube. The anode connection is made externally directly to the anode: in this way the highest voltage is eliminated from the seal. The valve in this form is very much smaller both in length and diameter than the corresponding glass valve. A new method of fixing to the moulded base has also been introduced, in which the valve is held in a compressed rubber ring. This helps to prevent external vibrations from reaching the valve, and by avoiding the use of cement, reduces the risk of the base becoming loose.

(ii) CONSTRUCTION OF A.C. "CATKIN" MAINS VALVES.

A detailed description of the construction of the

Fig. 3.—Components for the screened grid A.C. "Catkin" mains valve.

new type of A.C. mains valves will help to make clear how these general principles have been applied. Fig. 3 shows a complete set of components for the MS4B A.C. mains screened grid valve.

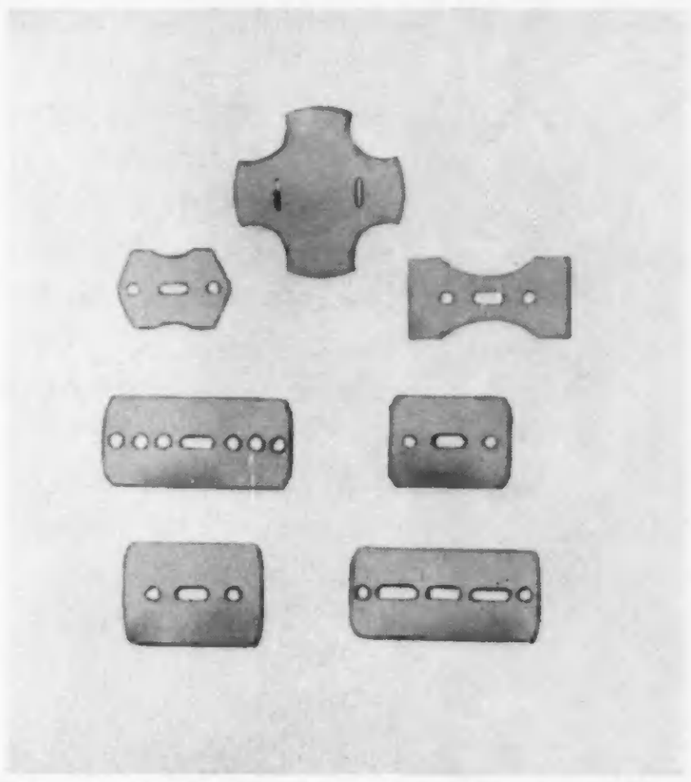


Fig. 4.—Mica insulators used in one of the "Catkin" valves.

Grid-cathode assembly. In mains valves the cathode takes the form of a nickel tube coated externally with the electron emitting material—a mixture of strontium and barium oxides. A new and more efficient form of coating is used, which enables the cathode to be run at a lower temperature and also allows the use of larger inter-electrode clearances, leading to greater uniformity. The cathode is supported axially in the control grid by two mica insulators. Fig. 4 shows a number of these insulators used in different types of valve. They are stamped with great precision, the central hole being used to locate the cathode, whilst the grid wires pass through the other holes. The profile of the mica is made to be a push fit inside the anode, the slight flexibility of mica rendering it particularly suitable for this purpose. The control grid is similar to those used in the latest glass valves, the damping wires are straight, and after passing through the holes in the mica they are slightly flattened to retain the mica in position, as shown in fig. 5. The tungsten heater, inside the cathode, is welded to a nickel loop for assembly. These two welds, and the weld to the cathode lead are the only welds in the electrode system.

Steel and mica clamp. The grid wires, heater and cathode leads are held in a jig whilst a steel and mica clamp is pressed round them. Fig. 3 shows the stamped steel member and the mica insulators before forming the finished clamp, which is shown in fig. 5. Copper-clad nickel steel wires are welded to the electrodes below the clamp and this operation completes the electrode assembly for a triode valve, the complete unit also shown in fig. 5 being ready for insertion into the anode. In the case of the screened grid valve the construction is similar, but the top mica fits inside the screen whilst the bottom mica fits in the skirt and abuts against

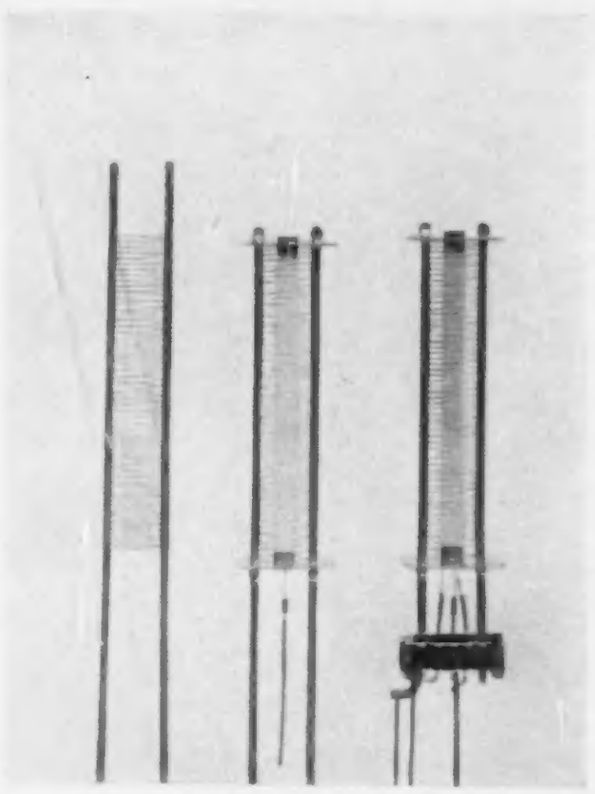


Fig. 5.—Stages in assembling the grid-cathode system.

the shoulder, thus determining the position of the assembly in the screen. The screen itself shown in fig 3 is hexagonal in shape, with solid sides to give the minimum grid-anode capacity. Another mica insulator is attached to the top of the screen, and this fits tightly in the anode. The skirt of the screen fits closely inside the glass tube and locates the lower end of the electrode system. The con-

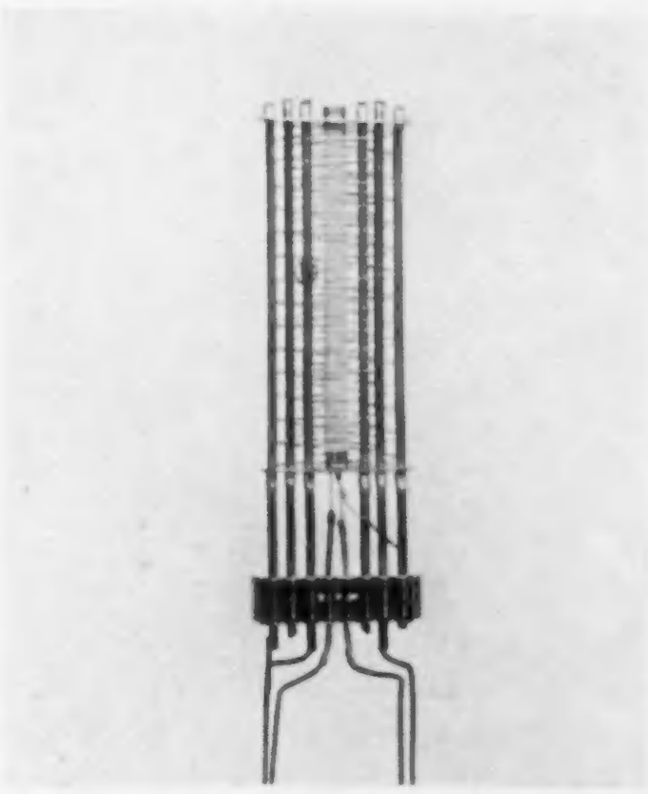


Fig. 6.—Assembly of the pentode cathode and grids.

struction of the pentode is shown in fig. 6 and is similar to that of the triode, the three grids all passing through both top and bottom micas, which in turn register inside the anode. All electrode components are subject to very stringent tests both

for quality of material and accuracy of dimensions before being passed to the assembly benches. In order to avoid distortion during assembly, the electrodes are held firmly in a jig throughout the operations.

Anodes. The anodes of "Catkin" valves are solid

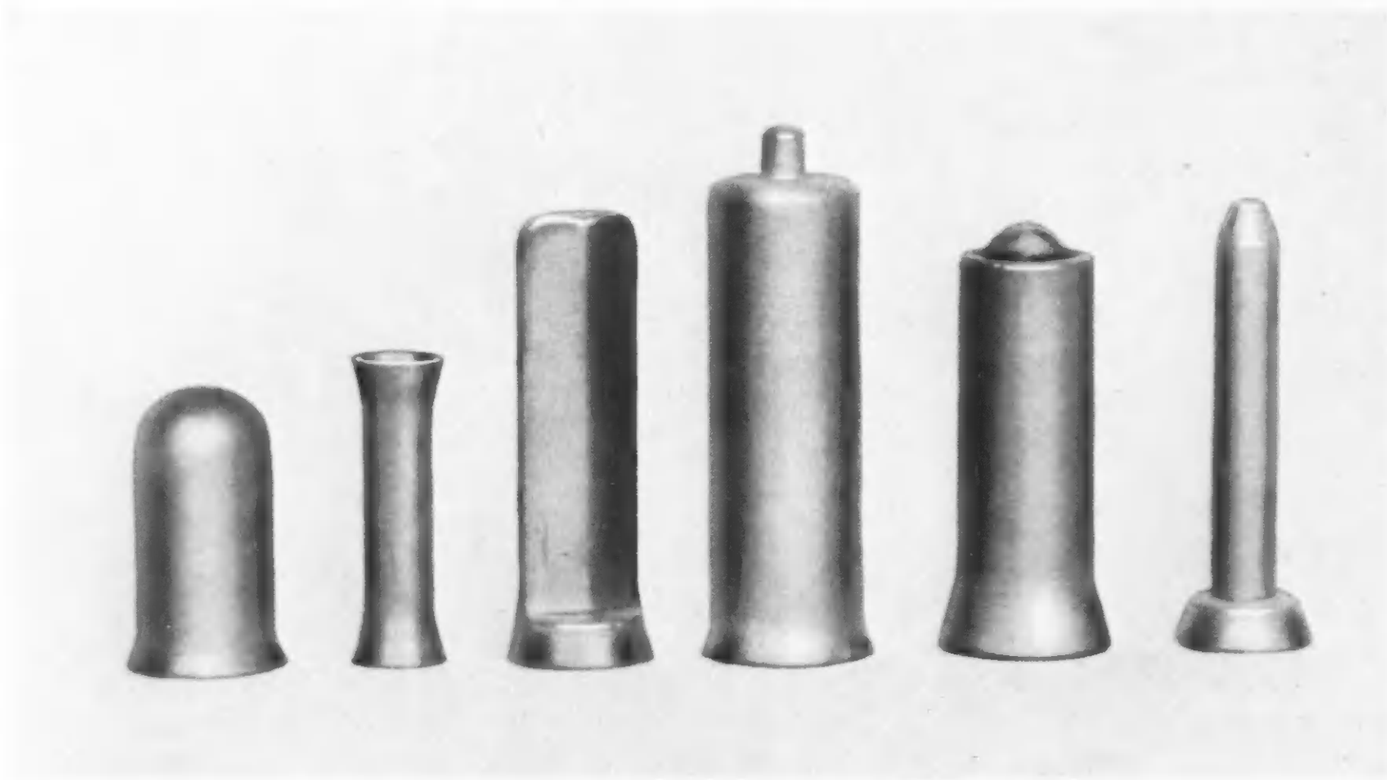


Fig. 7.—Copper anodes for "Catkin" valves.

drawn from high quality copper sheet, and are usually of cylindrical form. This process lends itself to production of very high accuracy, and the dimensions of the anode can be maintained within much closer limits than by the usual method of welding blanks of thin material. The copper is of sufficient thickness to withstand atmospheric

Fig. 8.—Flared glass tubes for circular seal.

pressure at the high temperature of the exhausting process, and consequently has a large factor of safety at the working temperature.

Fig. 7 shows a variety of the copper anodes used. The open end of the anode is slightly flared and the edge tapered where it is joined to the glass.

Glass to metal joint. In order to join the glass to the copper the thin edge of the anode is coated with potassium borate, to protect it from oxidation; this edge and the end of the glass tube are made red hot in a gas flame and then brought together. The glass wets the borated copper and forms a joint which, after suitable annealing in an electric oven of special construction, is both vacuum tight and strong. In spite of the difference in expansion of the glass and the copper the joint will withstand large changes in temperature owing to the ductility of the thin copper flange. The strength of the joint is shown by the fact that the glass itself will break before it can be parted from the copper. After joining, the inside of the anode, which has become oxidised by the heat, is cleaned by pickling.

Circular Seal. The electrode assembly is now inserted in the anode and the open end of the glass tube is closed by sealing into it a specially flared mushroom shaped exhaust tube. Various sizes of these are shown in fig. 8. The diameter of the mushroom is so designed as to leave room for the leading-in wires which are spaced round it, the edges of the two glass members being sealed together. The copper anode, glass foot tube and mushroom shaped exhaust tube are carefully gauged and graded to ensure accurate joining on the machines, which are of novel design and construction. Since the leading-in wires are used solely for carrying current, and do not contribute to the mechanical support of the electrodes, they can be quite fine and no stress is applied by them to the glass. The spacing between these wires is the maximum attainable for a valve of given diameter, and the anode is insulated by the full length of the glass tube. This form of seal therefore gives very perfect insulation between electrodes, also the joint made by the mushroom shaped exhaust tubing is much stronger than that of the exhaust tube in the " pinch " of a glass valve. The assembly before and after completing the seal is shown in fig. 9.

Exhausting. The valve is now ready to be evacuated on automatic pump machines. The new construction also leads to a simplification in this process. It is essential in order to remove all the occluded gases, that during the pumping operation each part of the valve should be heated to a much higher temperature than it attains when the valve is operating. Any evolution of gas during the life of a valve will lead to failure. Glass valves can only

be baked to about 450° C. since the glass bulb will collapse at higher temperatures. The electrodes, however, may operate at 500° C., and special methods are adopted to raise their temperature to a red heat during exhaust. One of the most usual methods is eddy current heating by means of a high frequency coil placed around the outside of the bulb. The new valves, however, run so much colder in operation, owing to the air-cooling of the anode, that they can be effectively out-gassed at much lower temperatures. Moreover, owing to the absence of the glass bulb, which itself is one of the chief sources of gas, they can be baked at higher temperatures than glass valves. Eddy current heating is therefore dispensed with and the valves are simply baked for a few minutes at 480° C. during the exhaust process.

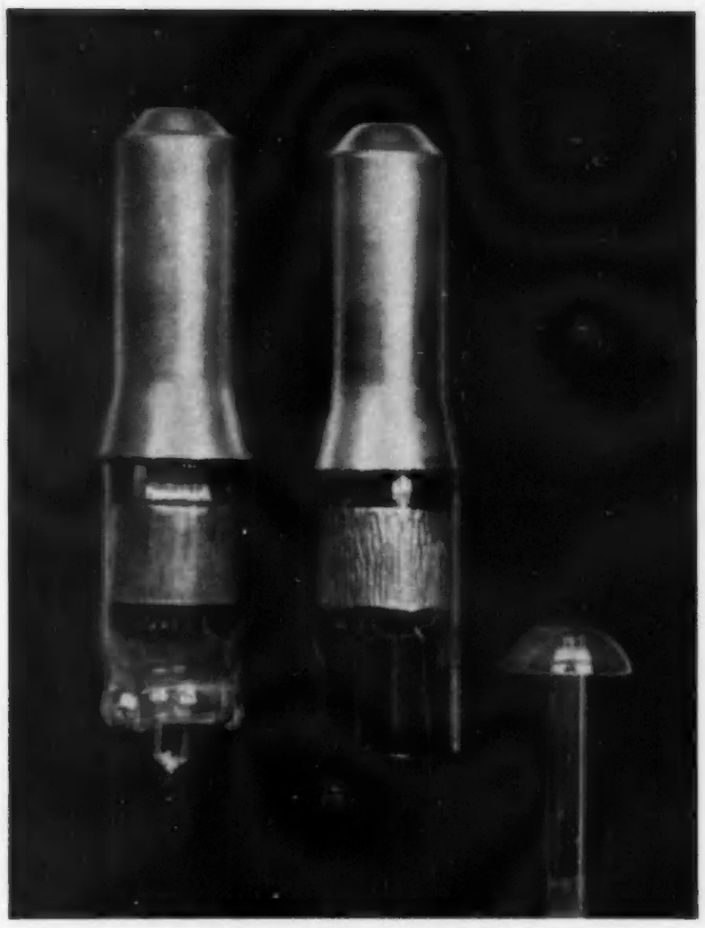


Fig. 9.—Glass mushroom and completed circular seal.

Capping and Ageing. After sealing off from the pump the valve has to be capped before going through the seasoning and ageing processes. The cap or base is usually attached to a glass valve by means of cement, and difficulty is experienced in preventing this from working loose. A new method has, therefore, been developed in which the base is attached by means of a compressed rubber ring. Rubber has the property of adhering more and more firmly to glass with time, and this method removes the risk of loose bases, while the life of the rubber ring exceeds that of the valve. The rubber mounting also helps to protect the valve from external vibration and so reduces microphonic noise. The new method of capping will be understood from fig. 10. The thin metal shell has a rubber ring held between a groove and the flanged top, into which the valve is inserted in a press. A bakelite insert carrying the usual 5 pins is introduced at the other end of the shell, which is spun over so as to retain it permanently in position.

Fig. 10.—Components and valve assembled in base.

When one of these pins forms the anode terminal, connection is made by a wire brought down inside the shell from a metal ring gripping the anode. In screened-grid valves the anode terminal is customarily at the top. This terminal takes the form of a brass cup which is heated and shrunk on to the top of the anode, thus making direct and permanent contact. Finally, the outside of the anode is covered with a layer of black insulating enamel, as a protection against shock should the valve accidentally be touched when in operation. The seasoning, ageing and testing processes follow the

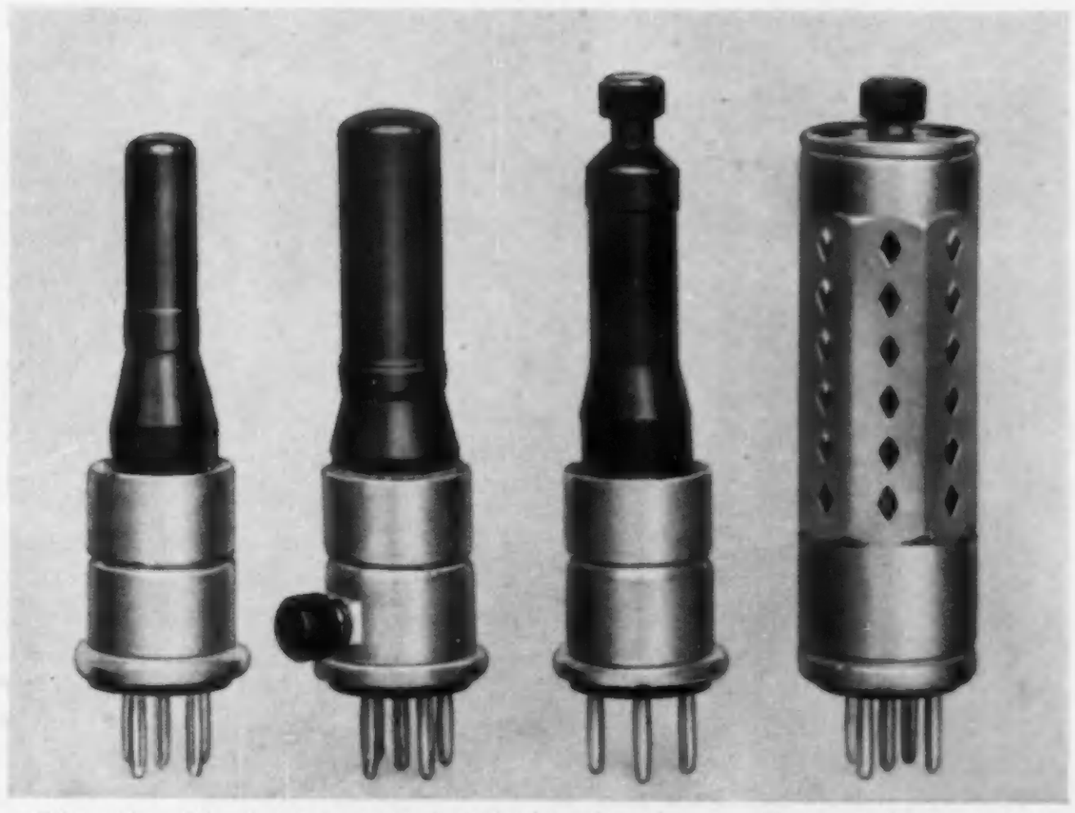


Fig. 11.—Various types of "Catkin" valves. From left to right—MH4, MPT4, MS4B and VMS4 in canister.

usual practice adopted for glass valves, but owing to the smaller size of the new valve the machines used occupy less space.

The Metal Canister. In the form just described "Catkin" valves are equivalent in capacity and characteristics to the corresponding glass valves which they are intended to replace. It is now a common practice to coat the bulb of glass valves externally with a film of metal. This metal coating is connected to earth or to the cathode pin and provides an electrostatic shield around the valve.

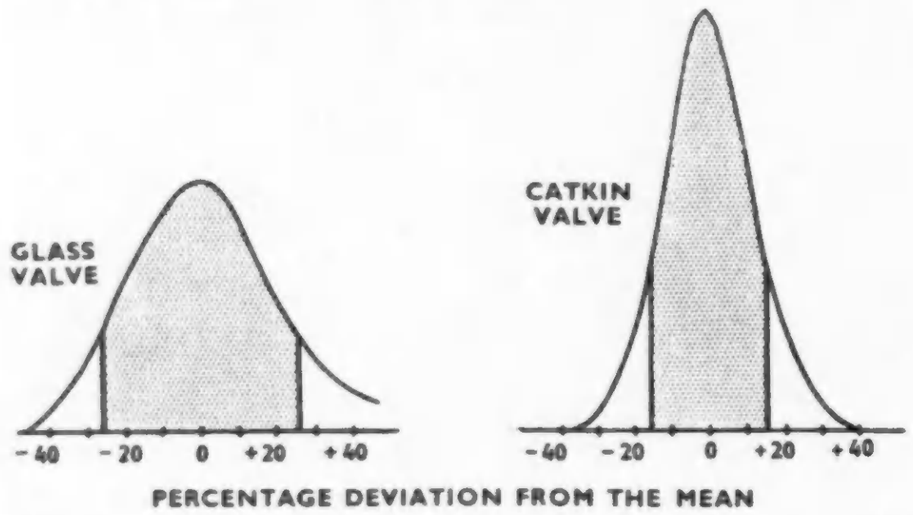


Fig. 12.—Curves showing percentage deviation from the mean anode current of 400 glass valves and 400 screened grid valves of the new type.

Fig. 13.—Glass MPT4 type valve and the corresponding "Catkin" valve showing relative sizes.

In the "Catkin" valve a metal canister shown in fig. 10 is placed over the entire valve and spun onto the base so as to fix it permanently. The upper end carries an insulating washer which locates the anode centrally, and the sides of the canister are perforated to allow free circulation of air to the anode. This canister gives better shielding than metal spraying, and also protects the valve from damage. A group of the new valves with and without the canister is shown in fig. 11.

(iii) CHARACTERISTICS OF "CATKIN" VALVES.

The earliest examples of the new valves to be introduced on the market were 4 volt A.C. Mains valves, designed with the same characteristics as the corresponding range of glass valves which they were intended to replace. This range includes the MH_4 triode, MS_4B and VMS_4 screen grid valves, and the MPT_4 pentode. The latter has been

Fig. 14.—Relative sizes of cartons in which glass MPT4 valves and the corresponding "Catkin" valves are packed.

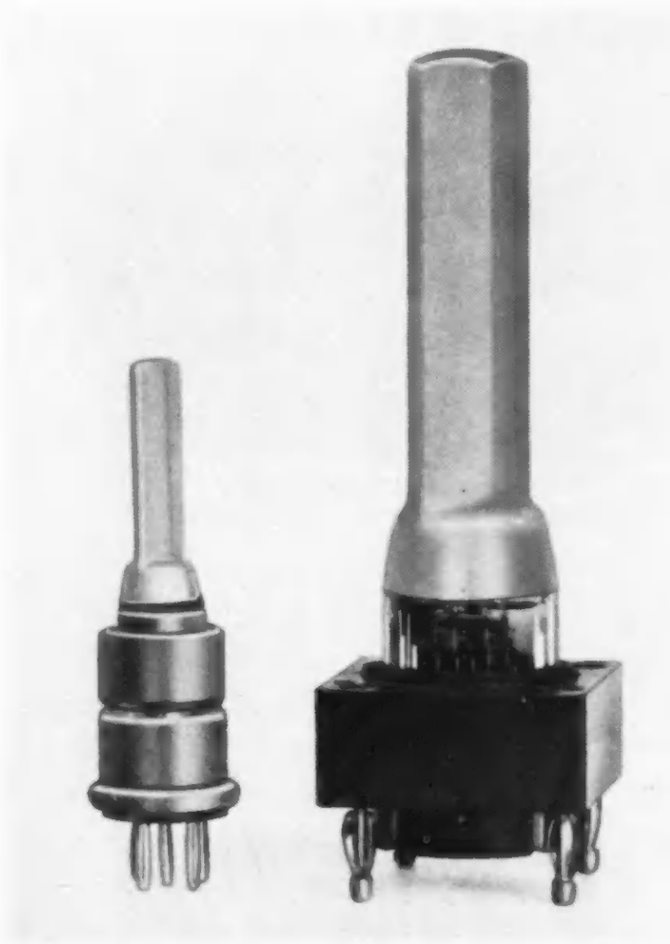


Fig. 15.—100 watt "Catkin" power valve in comparison with the A.C. mains triode.

redesigned to work at a higher screen voltage than the glass valve, whilst still being suitable for replacing the latter.

Uniformity. Whilst the mean characteristics are the same as those of their glass counterparts it is possible to manufacture "Catkin" valves to much closer tolerances.

This is illustrated by the curves for anode current in fig. 12, which show the spread in anode current in 400 glass valves and 400 of the new valves taken at random. The vertical ordinates show in each case the percentage variation from the mean necessary to include 90 per cent of the production. This variation is ± 15 per cent for the "Catkin" valve compared with ± 25 per cent for the corresponding glass valve. Such an increase in uniformity is of great advantage since the valves will replace each other without any readjustment of the set, a feature which is becoming of more importance owing to the increased sensitivity of modern sets.

Size. "Catkin" valves are considerably smaller both in length and diameter than the corresponding glass valves, and fig. 13 shows the comparison in the case of the MPT4 type. In view of the trend of modern set design towards using a large number of valves, this is an important feature and should lead to an appreciable saving in space.

Microphonicity. The small size of the valves combined with the rigid location of the electrodes and the rubber mounting, entirely eliminates microphonic noise and the familiar "howl" in the loudspeaker when a valve is touched no longer occurs.

Packing. The same factors together with the absence of the glass bulb makes it unnecessary to pack the new valves so elaborately. They are wrapped in corrugated paper and packed in a closely fitting carton; they can be then sent by rail or post without any further protection. The standard cartons for MPT4 valves of both glass and the new types are shown for comparison in fig. 14. The reduced packing not only saves cost in transport but also saves space in stores and factory.

The principles of construction used in "Catkin" A.C. mains valves are of general application, and other types of valve are being developed on the same lines. The air-cooled anode offers particular advantages for power valves, where the dissipation of heat from the anode is a limitation in glass valves. Fig. 15 shows a power valve capable of dissipating 100 watts made with a similar construction to the mains triode shown beside it for comparison. In other types of valve the strength, small size and uniformity achieved by the new construction each has its special advantages.

Vertical Spindle Motors for Southampton Docks.

Four 1,250 h.p., 6,600 volt, 3 phase, 50 cycle, vertical spindle synchronous induction motors loaded up for despatch to Southampton where they are to be installed in the new giant graving dock for driving pumps.

The Use of the Motion Camera for Testing Electrical Apparatus.*

By W. WILSON, M.Sc., B.E., M.I.E.E., M.A.I.E.E.

Development Dept., Witton Engineering Works of The General Electric Co., Ltd.

THE kinema camera, and similar recording cameras, are of great use in connection with the testing of electrical equipment, and are destined to play an increasingly important part in such work. Their principal uses are, first, the recording of the visual results of tests, more especially those effects which may be too transient for reliable detection by the eye; and, secondly, the keeping of a continuous and simultaneous record of the readings of a comparatively large number of meters during a long test cycle. A third function is the instruction of operators in the management of intricate pieces of apparatus; while propaganda and advertisement films exemplify a fourth use which has become quite an extensive one but does not call for further reference in this article.

Tests belonging to the first category may be exemplified by those on electrical circuit-breaking apparatus, such as large oil-immersed breakers, high-speed air circuit breakers, fusible cut-outs and lightning arresters. In all these, the significant part of the test lasts only a short time, such as from one cycle to seven cycles (20 milli-seconds to 140 milli-seconds), and a complete record can, therefore, be afforded by only a few feet of film. The data supplied by the photographic record include the nature and duration of the arc (in the case of an air-break apparatus), the emission of flame, smoke or molten metal, the duration and speed of any visual effects, and, not least important, the moving or springing of the various parts. The record is especially valuable in that it is able not only to detect such occurrences, but to measure with a close degree of accuracy their dimensions and duration.

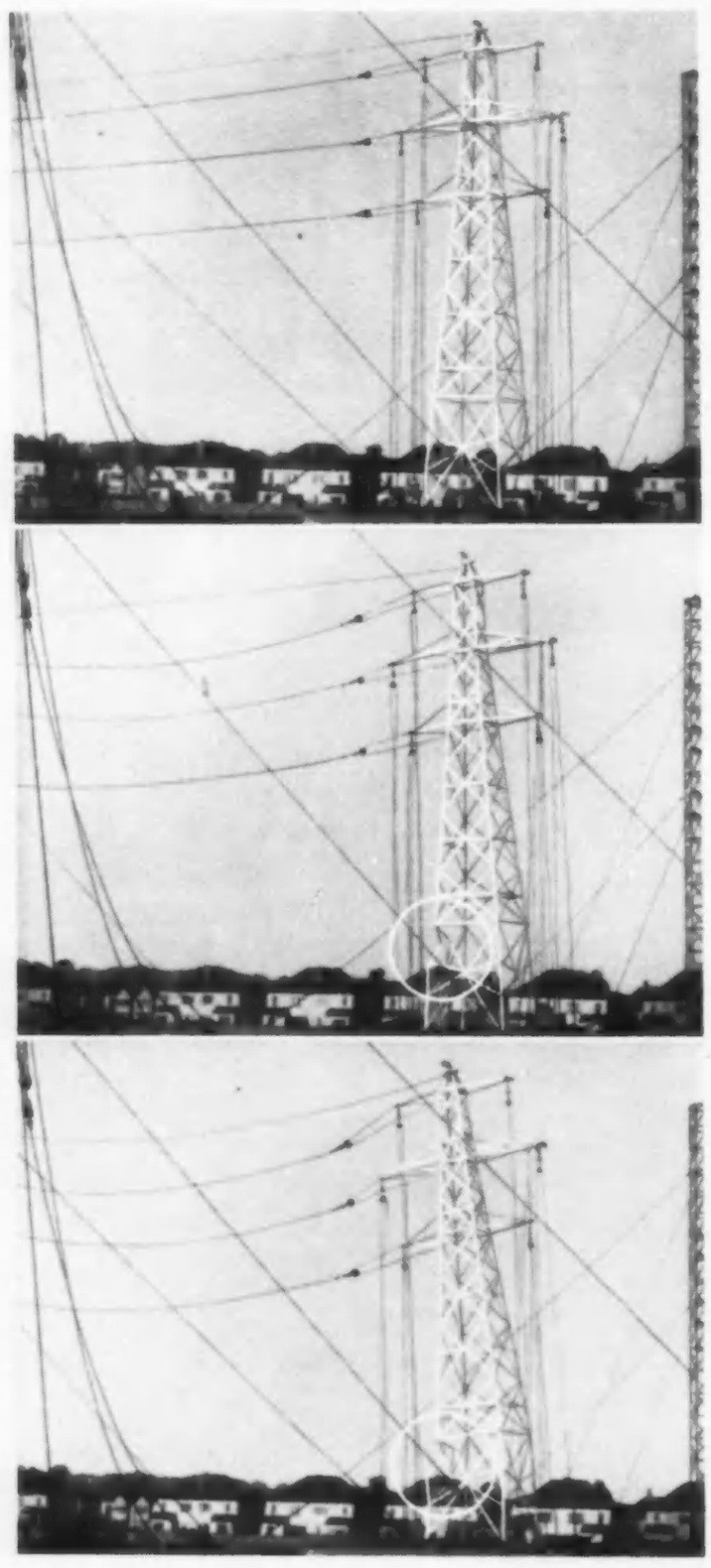


Fig. 1.—Part of a kinema camera film showing the failure of a 132 k V Grid tower on test. In the lower two illustrations the failing member is ringed round in white.

An excellent example of such tests has already been published by Torchio.† In these, the heavy current-carrying capacity of certain large oil switches was measured in air by passing currents of the order of 100,000 amperes through their locked contacts, and photographing the result by the kinema camera. In order to record the action at every half cycle, the taking speed was increased to 50 frames per second, and the shutter was synchronised with the positive and negative peaks of the 25-cycle current employed. This also had the advantage that the reproduction in the projecting lantern took place at less than one-third the taking speed, and the happenings could thus be the more closely studied. As the current and voltage values were simultaneously recorded by means of the oscillograph, it was possible to correlate the arc flashes and the general behaviour of the models with the changes in the electric circuit; and conclusions were drawn which had important consequences in circuit breaker design.

When a more or less elaborate structure is being tested, it is important to know which member fails first, and it is frequently impossible to do so without taking a continuous photographic record. Several extracts from such a film are

* Paper read before the British Association at Leicester, on September 8th, 1933.

† See *Journal A.I.E.E.*, vol. xl, page 61, 1921.

given in fig. 1, showing the sequence of events during the failure of a 132 kV Grid transmission tower. This example formed one of a series of tests to destruction that were made at the G.E.C. Research

Fig. 2.—Single frame of a film showing the breaking of a valve electrode due to mechanical shock.

Laboratories at Wembley on all types of tower before the design of each was standardised.

A somewhat similar method is adopted in investigating the cause of accidental breakage in the case of more or less fragile articles, such as valve filaments. In the early days of the dull emitter valve, the effect of various kinds of mechanical shock upon the assembled valve was explored by means of the kinema, and fig. 2 shows a single frame from one of the test films.

In tests on electric apparatus, the occurrence of arcing is the most common visual phenomenon, and by virtue of its high luminous intensity, it lends

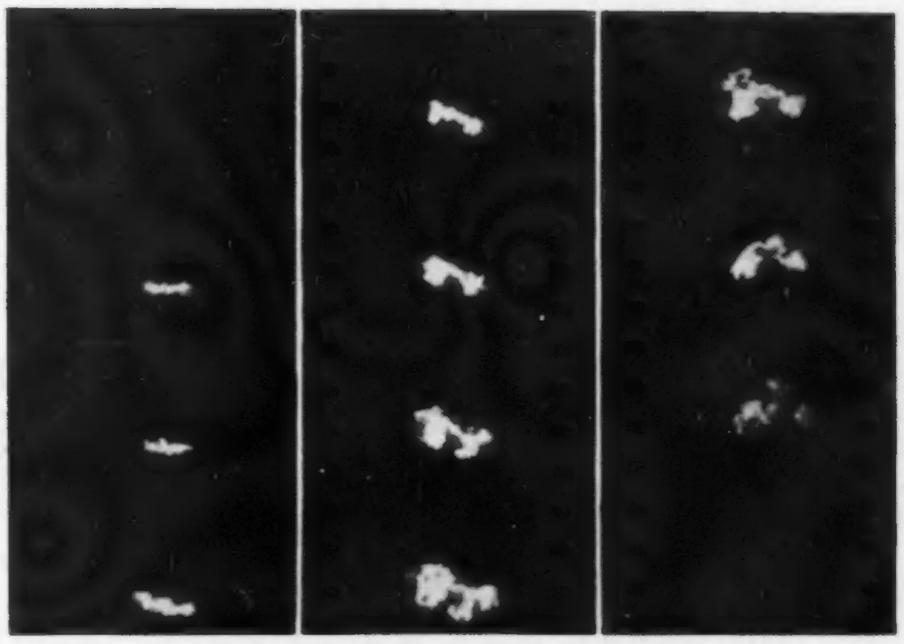


Fig. 3.—Part of kine-film recording 132 kV short circuit in air.

itself readily to photographic recording, imprinting itself upon the film even under highly adverse conditions. The example forming fig. 3 consists of twelve frames from a film recording a dead short circuit to earth at a Grid sub-station, and was actually taken out-of-doors while the blizzard of Feb. 24 last was at its height. The arc was struck between a pair of horns by bridging them with a fuse wire prior to the closing of the main breaker. Besides showing the successive shapes assumed by the arc while it was extending, the film also indicates the relative intensity at the various stages, and its duration. The full extension however, is not evident in this particular series of photographs, since the gale was blowing towards the camera; the total length of the arc being in the neighbourhood of 14ft. to 20ft. In this case, extinction was brought about by the opening of the circuit-breaker, and the last three frames illustrate the fading process following the interruption of the power supply.

Since the duration is short and the luminosity intense, most arcing tests can be very conveniently recorded by means of a simplified form of motion-picture camera, which renders higher speeds practicable, and requires only a single glass plate of say half-plate or whole-plate size. A camera of the type, illustrated in fig. 4, was designed in the G.E.C. Development Laboratory at Witton, and consists of twelve similar lenses, each of which produces a separate image and is uncapped in turn by means of a simple rotary disc shutter, driven by an electric motor. Field and armature regulation of the latter varies the shutter speed over a wide range. For

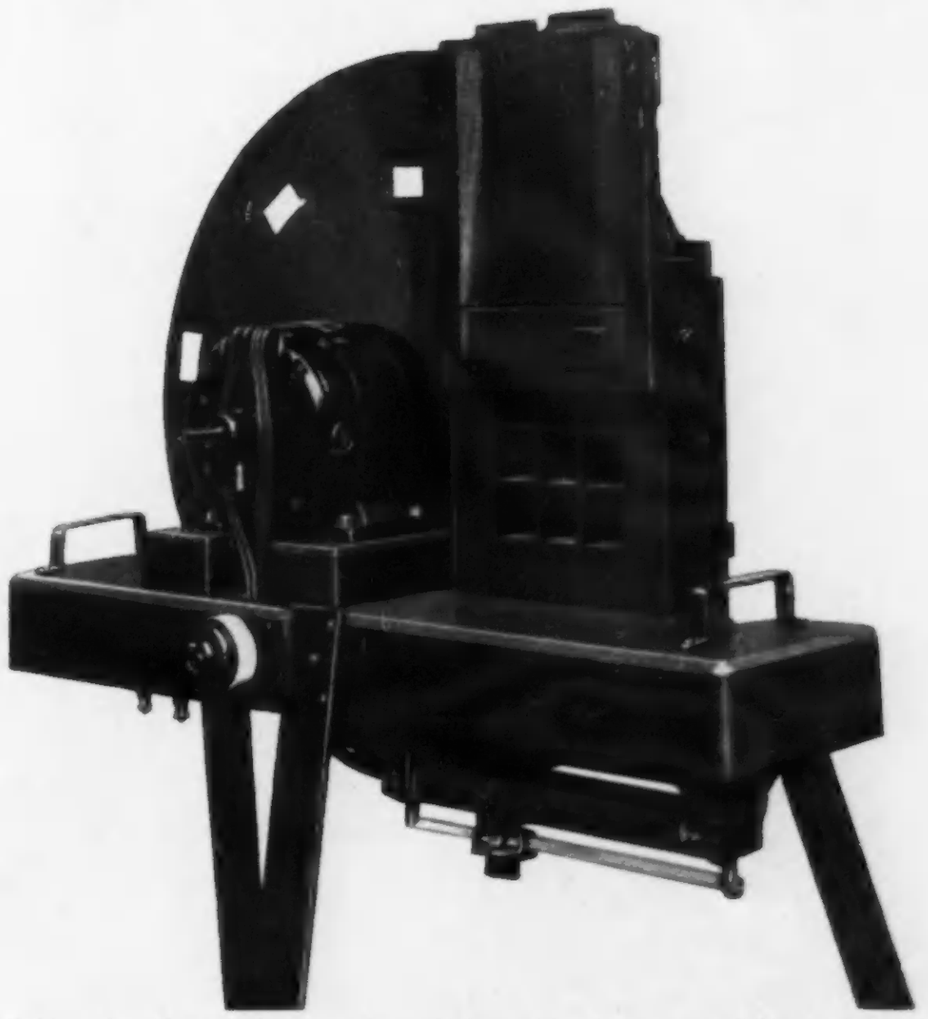


Fig. 4.—Experimental motion camera used for taking photographs illustrated in figs. 5 to 8.

example, 24 to 100 or more pictures may be taken per second, the speed being capable of exact measurement. The procedure during a test is first to run the shutter for a sufficient time to enable the apparatus and background to be satisfactorily photo-

graphed, and then to close the switch that initiates the test. Thus the consequent arc is superimposed on a clearly exposed image of the apparatus, and a complete set of data is the result. Figs. 5 to 8 are examples of such records.

Those shown in figs. 5 and 6 illustrate the difference between the interruption of direct-current and alternating-current circuits. They actually represent the melting of exactly similar fuse-wires by the same R.M.S. values of current, but the direct current effects shown in fig. 5 were recorded at the rate of 24 frames per second, and the alternating-current effects shown in fig. 6 at 96 per second. An alternating-current arc is the easier to interrupt because it passes through a zero-point twice per cycle. Since it is momentarily extinguished at these points, all that is necessary is to prevent it from re-striking, as contrasted with the task of positive suppression in the case of direct-current. For this reason, a direct-current fuse-wire, in general, is entirely consumed, while with alternating-current the wire is merely interrupted at one or more points, leaving considerable portions of the wire unaltered. It will be observed that the extinction of the direct-current arc is complete in eight frames, representing one-third of a second, while the

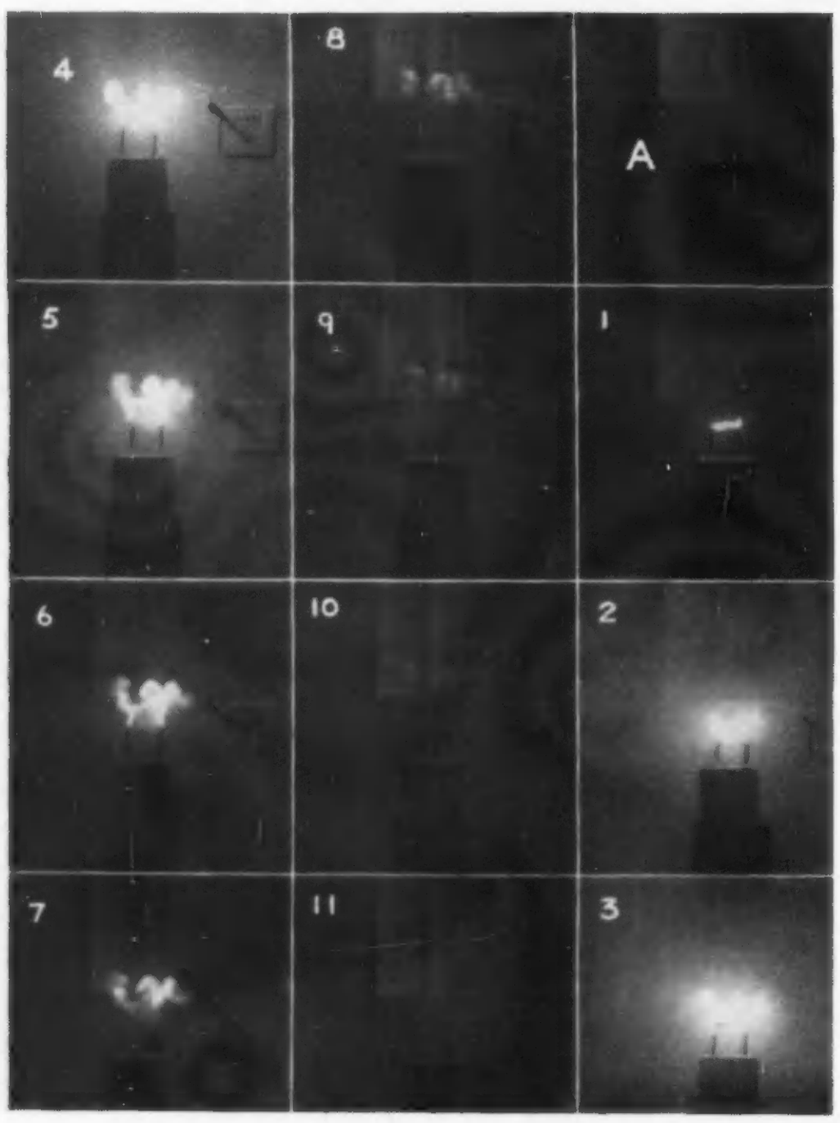


Fig. 5.—Melting of open fuse wire by D.C. short circuit.

alternating-current arc is over in six frames, occupying only one-sixteenth of a second. Since the test may start anywhere in the plate, the frames are numbered to show the order of events.

These two figures also show a very interesting principle in connection with the rupture of an arc. The common theory is that it snaps at one point, very much like a stretched thread, and quite wrong

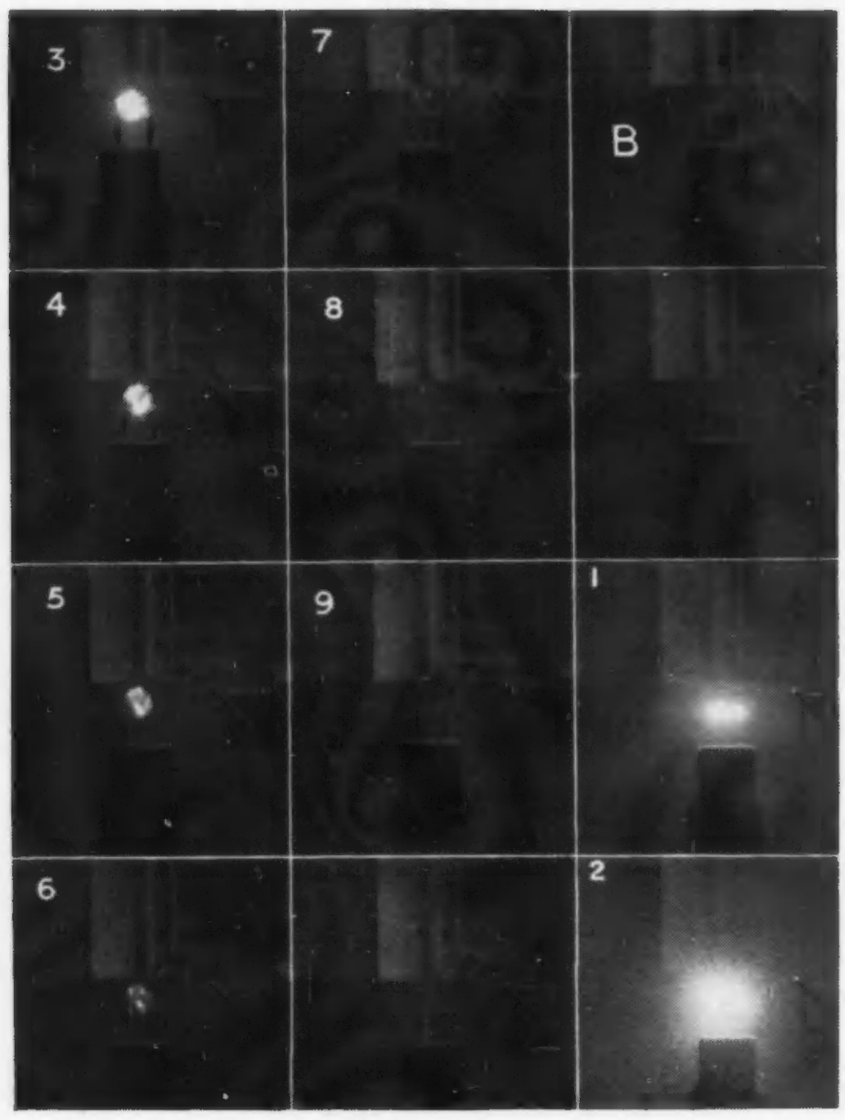


Fig. 6.—Melting of similar fuse wire to that shown in fig. 5 by A.C. short circuit of same amperage.

conclusions have been based on this assumption. The present photographs prove that this is not the case, but that the arc persists until there is not sufficient electrical input to maintain its temperature and consequent ionisation, whereupon it fades away uniformly over its whole length.

The next plate, fig. 7, records the operation of a 660-volt direct-current lightning arrester having two brass horn-gaps in series, one of which is provided with a magnetic blow-out and the other shunted by a carbon resistance rod. The arcs were started by short-circuiting the gaps by means of fragments of tin foil, causing the large discharge of the first three frames. Then the gap on the left was damped out by its shunting resistance, while the vigorous motor action of the magnetic blow-out is evident on the right, in propelling the arc-stream mechanically out of the chute and elongating it to extinction.

One of the great advantages of photographic recording is its ability to give a comprehensive and definitely correlated account of the behaviour of all the pieces of apparatus concerned in a test, enabling, for example, cause and effect to be seen together. An instance of this is shown in fig. 8, where the protection of rotary converters by a high-

speed circuit breaker is analysed. The two large machines, running in series at 1,500 volts direct current, are visible in the background, and are

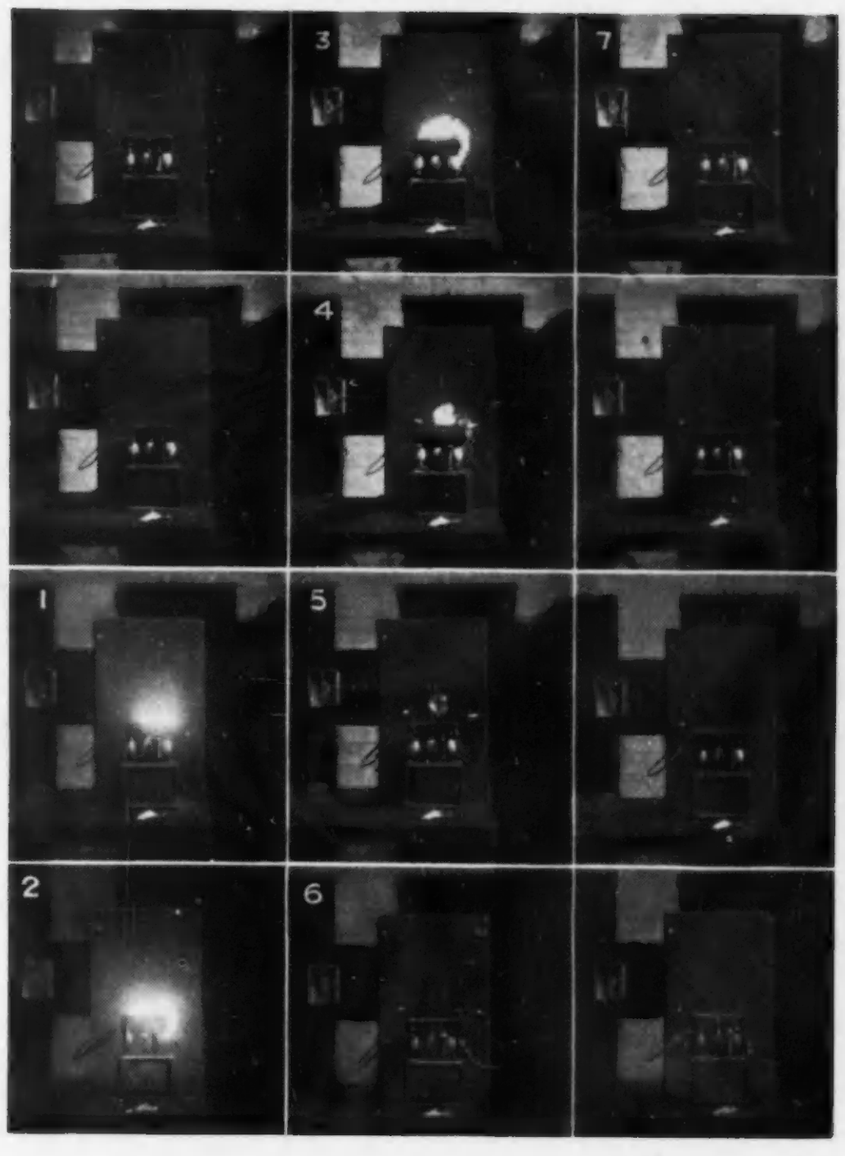


Fig. 7.—Operation of double horn type D.C. lightning arrester.

Fig. 9.—One frame of a kine-film showing a continuous record of measuring instruments taken during sea trials of the Q.T.E.V. "Queen of Bermuda."

among those supplying the power for the South African electrified railways. In order to obviate the highly destructive effects resulting from the flash-overs to which traction machines are subject, the air circuit-breaker seen in the foreground must be able to open its contacts and break the circuit in 0.01

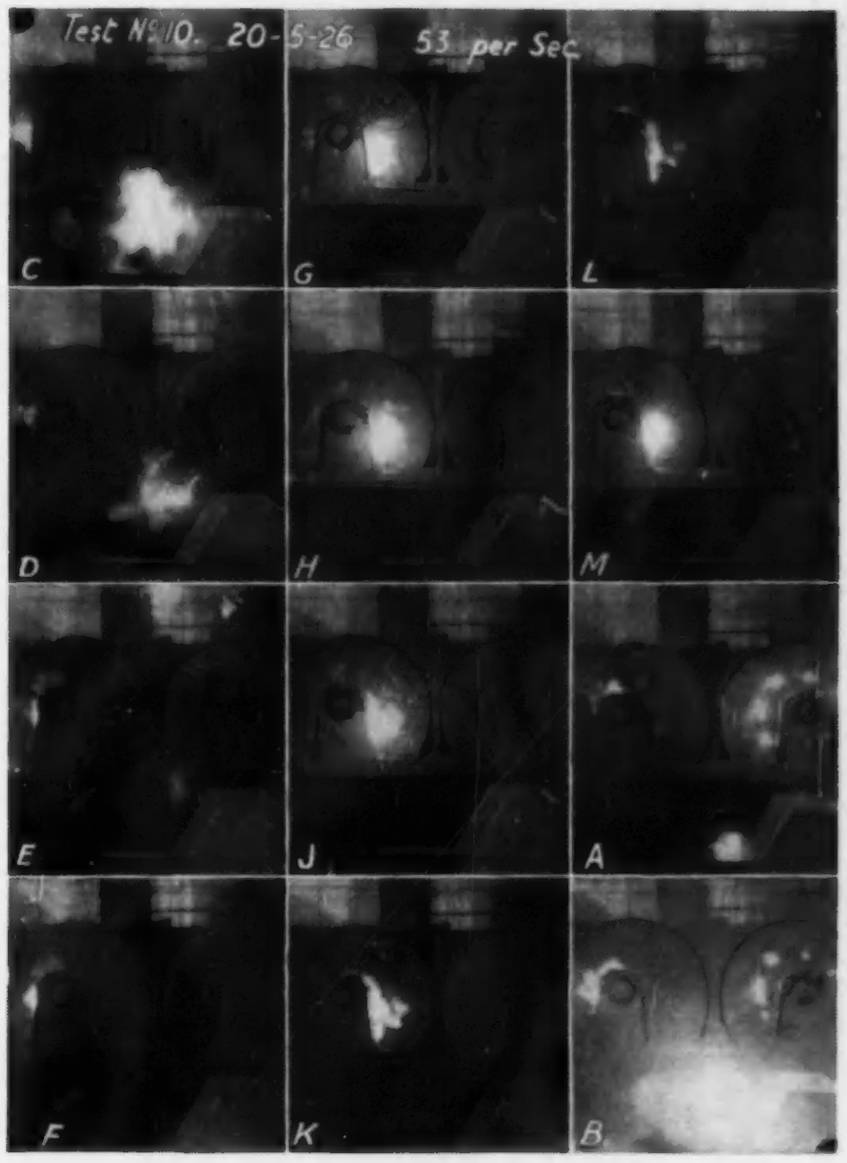


Fig. 8.—Flash-over of rotary converters and operation of high speed circuit breaker.

second or less. In frame A, both rotaries had just been short-circuited, and were beginning to flash-over, but it will be seen that the high-speed breaker had already begun to function. Only two frames later, viz., before 0.038 second had elapsed, the flash-over was extinguished and the circuit broken. The concluding frames E to M explained a curious apparent prolongation of this particular arc at the commutator of the left-hand machine, a phenomenon which was now seen to be due to a transient recrudescence of the flashover through a species of alternating current surge taking place while the circuit was actually broken.

An example of the second type of test film, namely, the simultaneous recording by the kinema camera of numerous quantities during a test-cycle, is illustrated in fig. 9. This shows an assembly of no less than seventeen instruments employed during the sea trials of the 19,000-ton electrically propelled quadruple-screw liner *Queen of Bermuda*. The ship was put through a specified series of manœuvres, including starting, varying speed, and sudden reversal, and the various meters indicated the time, helm position, reading of the ship's log, the voltage, excitation, and speed of each of the two alternators, and the armature current and speed of

each of the four motors. A study of the successive readings was of the greatest value in determining the transient effects at the various points of the cycle. The illustration is actually an enlargement of one frame of the film.

The third use of the kinema is one which is as yet in its infancy, but which promises to reach large proportions with the aid of the sub-standard types of projector, of which that using a 16 mm. film is probably the most serviceable. These smaller sizes all use non-inflammable film, and are portable,

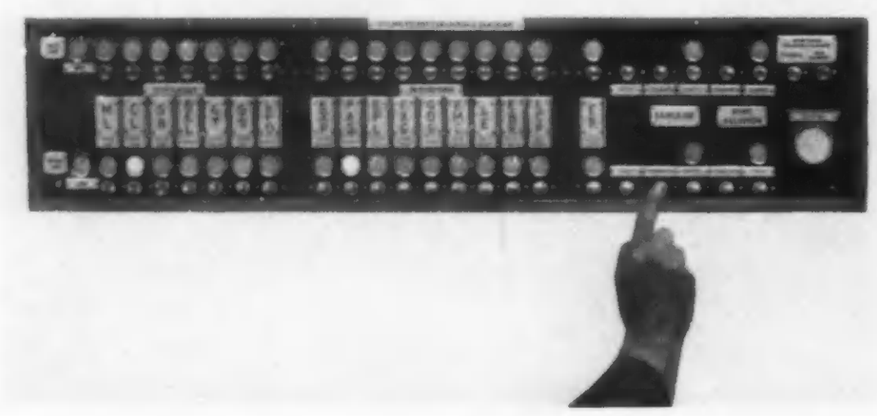


Fig. 10.—One frame of a 16 mm. film compiled to educate a control staff in the operation of a railway control system.

compact and inexpensive, with the result that they may be employed in a host of situations where the standard apparatus would be inadmissible. The first instance of the instructional functions of the film that came within the author's knowledge occurred during the installation of automatic telephony in Australia. One of the erecting engineers was a keen kinematographer and caused the process of "dialling" to be photographed and subsequently shown with suitable commentary at the picture-houses during their ordinary programmes. The results were so successful that this method of instruction has been adopted for much more elaborate apparatus. A good example of the latter is illustrated in fig. 10, forming one frame from a 16 mm. film compiled to educate the signalmen and other members of the railway staff in the St. Enoch district of Scotland, in the operation of the "Train Describer" system for electrically interlinking signal-cabins. This is a new method that much simplifies and expedites the transmission of the descriptions and destinations of trains passing through a section; track circuiting and automatic stepper switches being associated in bringing about a great advance as compared with existing schemes. Its operation for all purposes and in all contingencies was clearly exhibited in the film, which met the case with every satisfaction.

Finally, the kinema type of film is employed to record continuous tests involving indications of fluctuating currents, voltages, and other quantities, as well as movements of mechanical parts, whether in the form of travel over comparatively large distances or low amplitude vibrations. Such records are effected by means of oscillograph vibrators, and are thus really outside the category of motion pictures. An example is however given in fig.

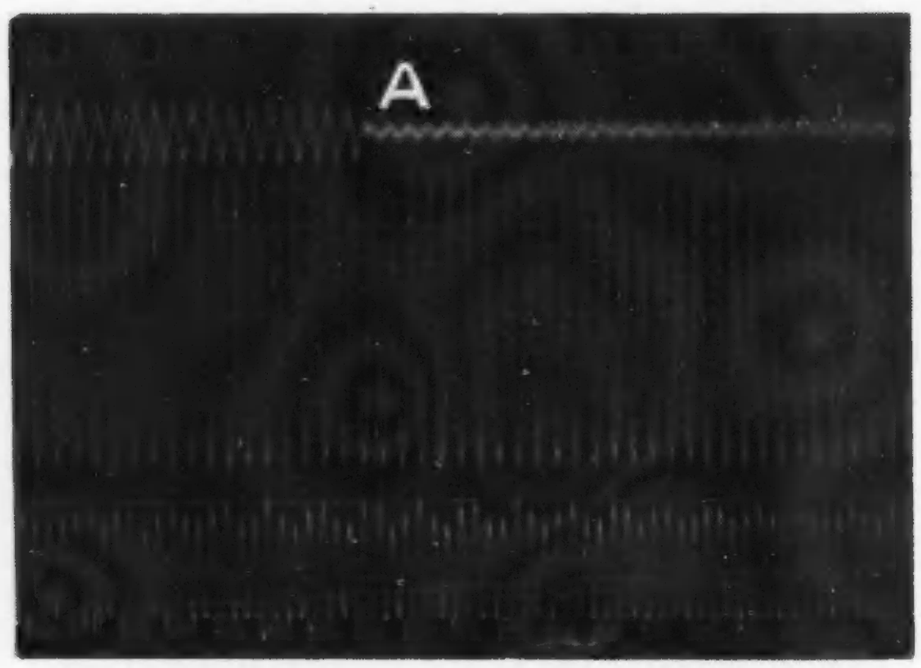


Fig. 11.—Illustrating the use of the kine-film to record continuous indications of currents, voltages and other quantities.

11 to illustrate this use of the film, being a short excerpt from a long strip taken in the Experimental Laboratory at Fraser & Chalmers Engineering Works, whereby the damped vibration of a steam turbine wheel was ascertained. The wheel was caused to vibrate about six nodal diameters by means of an electro-magnet excited from a variable-frequency motor-generator set, the applied frequency being recorded by the upper wave. Below this is the wave which gives the actual vibration of the wheel, and which was obtained by causing a portion of the wheel surface to function as the moveable plate of a small air condenser, varying the capacity in the instrument circuit; while the lower wave is the timing scale obtained from a 500-cycle timing fork. The portion of the film selected for reproduction is that where the electro-magnet was de-energised, and where the amplitude of the consequent vibration is therefore a maximum. From the data so obtained the frequency of the latter was found to be approximately constant at 358.5 to 358.8 cycles per second; while the damping factor, the real object of the test, was worked out as 0.213.

The above are only examples of the ways in which the motion camera can assist the investigator in connection with the development, design, and testing of electrical apparatus. Its use is extending and its services will undoubtedly be considerably more valuable in the near future.

Electrical Equipment for the British Grid.

PART I.—OUTDOOR SUB-STATION EQUIPMENT

By A. M. ANDERSON, A.M.I.E.E.,
Witton Engineering Works of The General Electric Co., Ltd.

This is the first of a series of four articles in which it is intended to describe the large amount of equipment the G.E.C. has supplied to the Central Electricity Board for use on the British Grid.

This equipment is of so comprehensive a nature that in the space at their disposal the authors have been able to deal with only the more typical examples of the gear installed.

THE completion of the last pylon for the British Grid on the 5th September, 1933, brings to a close the main constructional work on the greatest scheme of its kind in the world. For five and a half years, and at a total cost of £27,000,000, this gigantic undertaking has been under construction, providing employment, directly and indirectly, for 200,000 workers and giving a much needed stimulus to many British industries.

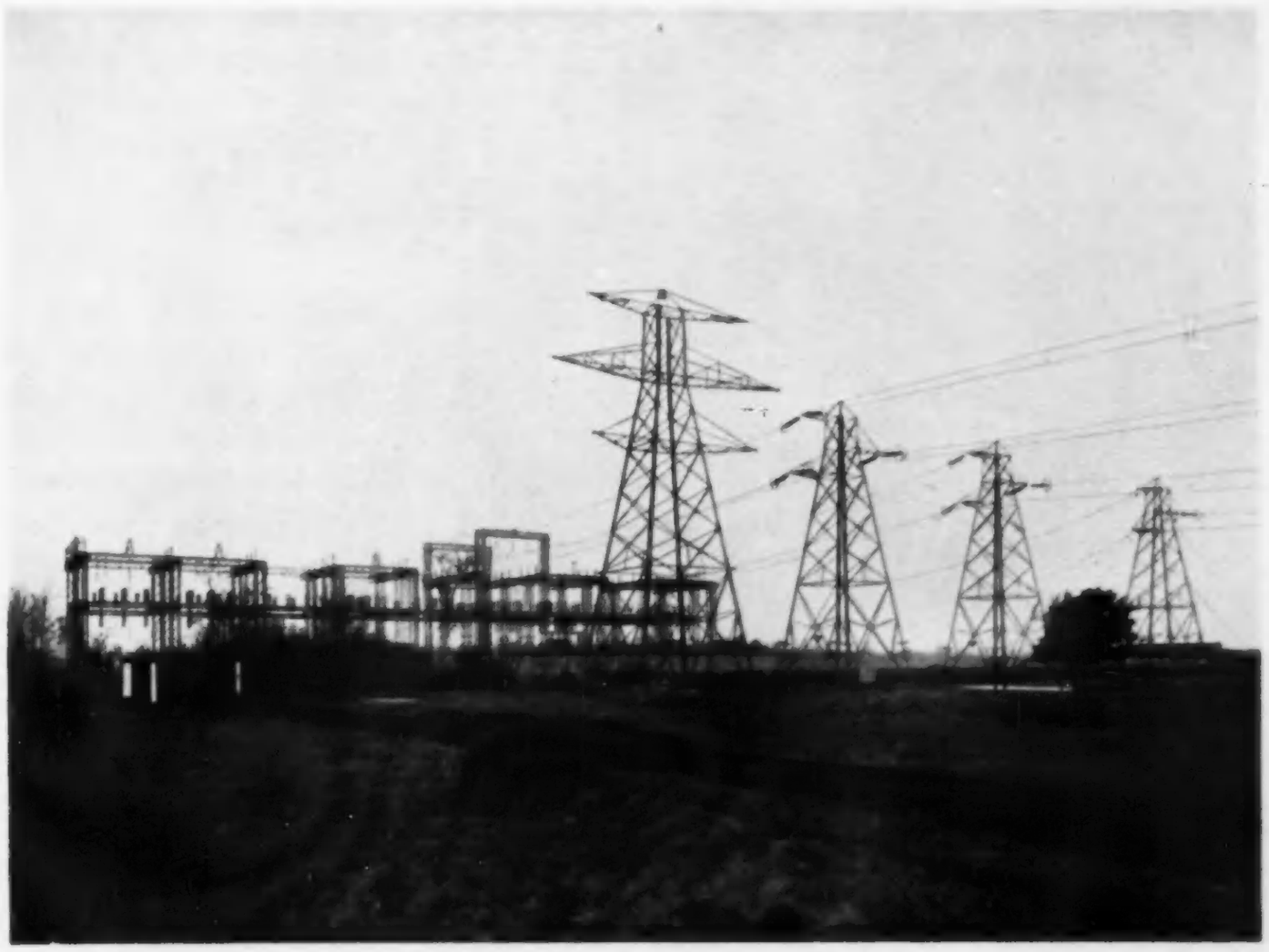
The objective, political and financial aspects of the Grid have been competently dealt with elsewhere. It is therefore intended in these articles to record the contracts entrusted by the Central Electricity Board to The General Electric Co., Ltd. The review of this work will be divided into four sections as set out below, the first of which forms the subject of the present article.

(1) *Outdoor Sub-station Equipment.*

Central England (132 kV switchgear).
South West England (132 kV switchgear).
Mid East England (132 kV transformers).
North West England (33 kV switchgear).
South Scotland (33 kV switchgear).

(2) *Towers, Transmission Lines and Cables.*

South East England (132 kV).
Mid East England (132 and 33 kV).
Central England (132 kV).
North West England (33 kV).
South Scotland (33 kV).
Also 132 kV and 66 kV oil-filled cable installations in London and North East areas.



G3678

Fig. 1.—A general view of Hams Hall sub-station on the Central England section of the Grid showing some of the interconnecting feeders.

(3) *Metering.*
Central England.
North East England.

(4) *Fault Protection and Communication.*
Central England (fault protection and communication).
South West England (fault protection).
North West England (fault protection).
Mid East England (fault protection).
South East England (communication).

OUTDOOR SUB-STATION EQUIPMENT.

Apart from differences in the detailed layout of the various sub-stations, the actual equipment installed in all stations which the G.E.C. has manufactured and supplied for the grid is essentially

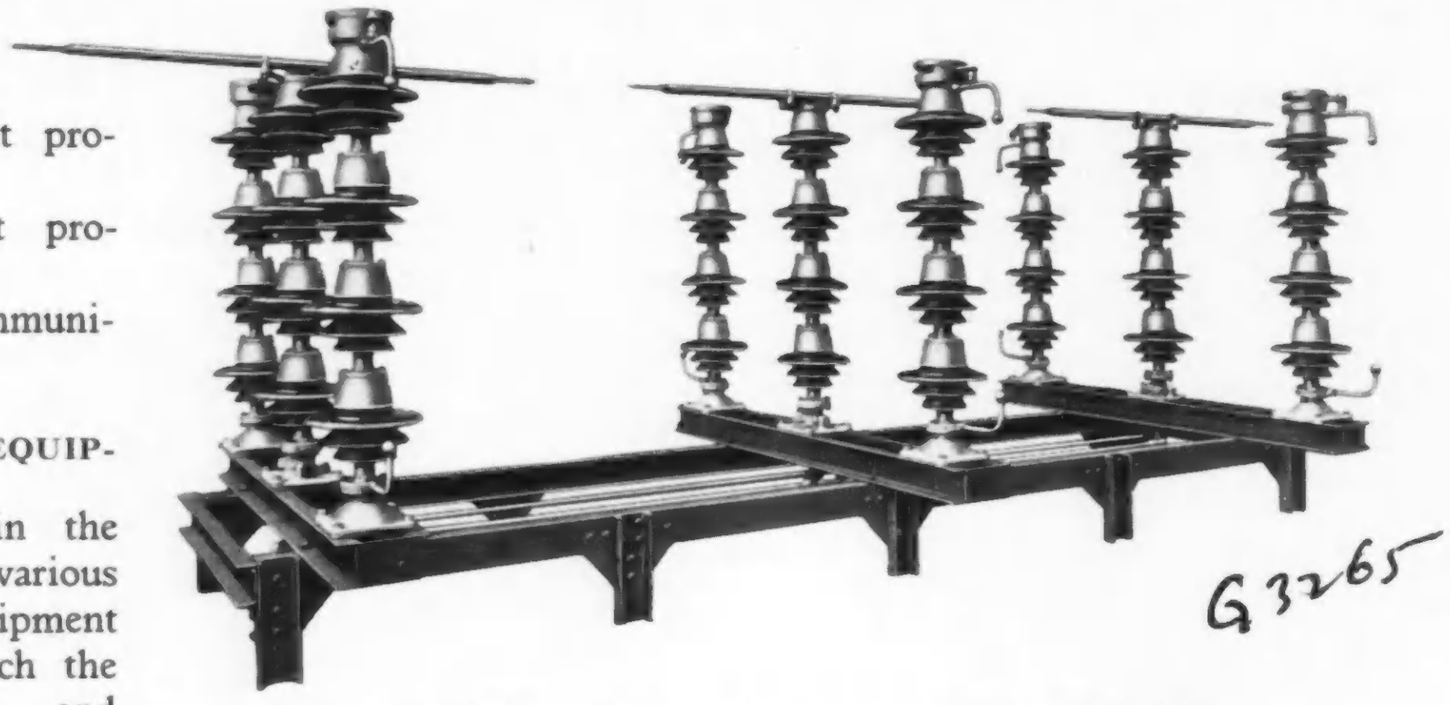


Fig. 3.—132 kV rotary isolating link as used on the primary lines of the Grid.

Fig. 2.—Single phase of a 132 kV, 1,500,000 kVA oil circuit breaker removed from tank. View shows the switch in the open position.

similar in design and construction. A total of thirty-one 132 kV outdoor stations have been so equipped, involving the manufacture of over one hundred 132 kV 3-phase oil circuit breakers of 1,500,000 kVA breaking capacity and approximately four hundred 132 kV 3-phase rotary isolating links, in addition to over fifty 132 kV earthing switches. Each of the 31 stations is also equipped with control switchboards and low tension switchgear together with metering and protective equipment.

Before describing the grid schemes in detail, the design and construction of the equipment installed will be briefly outlined.

OIL CIRCUIT BREAKER.

The 132 kV outdoor oil circuit breakers installed by the G.E.C. are of the type in which each breaker has a separate switch body and tank per phase, while each complete single phase unit can be replaced without disturbing the adjacent units. These breakers are arranged for remote electrical operation, but provision is made for manual operation of the complete unit in cases of inspection or emergency.

The top cover of each single phase breaker incorporates the breaker body and takes the form of a pressed steel dome which carries the operating mechanism, bushings, current transformers, etc. Gas vents with non-return valves and a contact position indicator are also fitted.

The tanks, which are circular in plan, are directly bolted to concrete foundations, and are designed for an internal pressure of 200 lbs. per sq. inch. Each tank contains 1,150 gallons of oil, while the contacts are so arranged that four breaks per phase are obtained. This is clearly illustrated in fig. 2 which shows the interior of a single phase unit.

The closing and tripping solenoids, D.P. contactor, discharge resistance and operating gear are arranged in an adjacent pillar. Complete interlocking protection is provided and is described later in this article.

ROTARY ISOLATING LINKS.

The 132 kV isolating links are of the rotary type. It will be seen from fig. 3, that there are three insulator posts per phase, the centre post carrying the blade which rotates in a horizontal plane,

Fig. 4.—Map of the Central England area of the Grid.

bridging the contact jaws of the two outer insulator posts when the link is closed. A double break per phase is thus obtained.

A feature of importance is that the contacts are bolted and not cemented to the insulators, so that in the event of damage to any portion of the apparatus a replacement can be made with the minimum of trouble and time.

INTERLOCKS.

In order to guard against faulty operation of isolators, a simple form of interlock is employed which embodies the use of Castell figure locks. The main purpose of the interlock is to prevent an isolator being opened or closed unless its associated oil circuit breaker is in the open position. This object is obtained by fitting locks to the isolators and oil breakers which engage with the mechanism so as to prevent their operation. As an example, reference to fig. 18 will show that oil circuit breaker 220 has on either side of it isolators Nos. 224 and 228. In order to prevent the operation of isolators 224 and 228 before the oil circuit breaker 220 has been opened, a lock is provided on the oil breaker which locks it in the open position. This lock bears the number 220 and can only be operated by a key bearing the same number.

Locks bearing similar numbers are fitted to isolators 224 and 228. These locks, however, are capable of locking the isolators in either the closed or opened position.

In all cases the locks are so arranged that when in the unlocked position the key is trapped in the lock and cannot be removed until the lock has been turned into the locked position, so that key No. 220 is always trapped in the lock on the oil circuit breaker when the latter is in the closed position. It is therefore impossible to obtain this key to unlock the isolators until the oil breaker has first been opened.

CENTRAL ENGLAND SCHEME.

The Central England Scheme provides for the construction, *inter alia*, of about 400 miles of primary transmission lines and 18 miles of secondary lines, involving the erection of 18 132 kV outdoor sub-stations. All these were completed in 1932 and are situated at Hams Hall, Ocker Hill, Nechells, Leicester, Ironbridge, Coventry, Nottingham, Spondon, Stourport, Wolverhampton, Bartley Green, Burton, Loughborough, Northampton, Stafford, Stoke, Warwick and Worcester. A map of the area showing the interconnected sub-stations is given in fig. 4. A total of nine selected generating stations are interconnected

(By courtesy of Messrs. Highfield & Roger Smith)

Fig. 5.—The remote indicating board at Wake Green Road, Birmingham. This board affords a visual representation of the conditions at all stations in the Central England area.

having an aggregate plant capacity of 553,500 kW, while the area system is connected to those in adjoining areas by lines to Bedford, Crewe and Gloucester. The consulting engineers for this scheme were Messrs. Highfield & Roger Smith.

The 18 sub-stations are of four main types known as High Double Busbar (abbreviated to H.D.B.), Low Double Busbar (L.D.B.), High Extensible (H.E.) and Low Non-extensible (L.N.E.).

Both the H.D.B. and L.D.B. types of sub-station are capable of being extended as and when the need arises, whereas the L.N.E. type is non-extensible and is definitely limited to two feeders. The H.E. type of sub-station may be extended to the H.D.B. type. Generally, the principle of design in the "high" type of sub-station is the use of steel constructions consisting of columns and cross-members for the support not only of the busbars and electrical connections but also much of the switchgear itself. Where land is expensive and the stations control many feeders and transformers, in particular if duplicate busbars are used, the "high" type of sub-station is usually adopted. On the other hand, it is self-evident that if a large amount of constructional steelwork can be avoided the maintenance costs in later years will be considerably reduced.

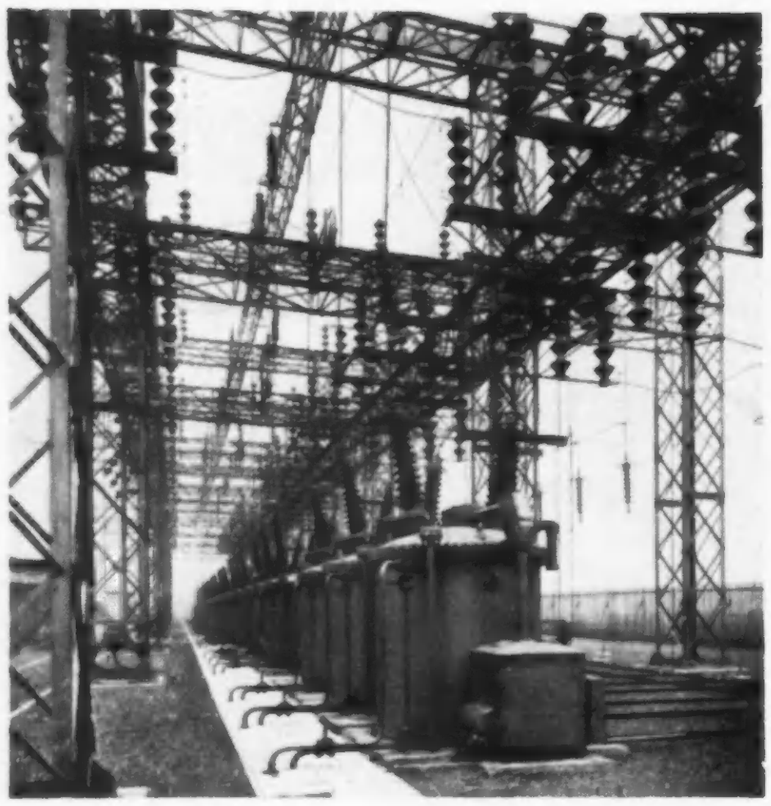


Fig. 6.—View of the nine 132 kV, 1,500,000 kVA, 3-phase oil circuit breakers installed at Hams Hall sub-station.

These considerations have led to the introduction of the "low" type sub-station, which had found much favour with the Central Electricity Board. With this design most of the steel members have been either eliminated or replaced by concrete pillars. Low sub-stations of all types have been made from simple single-switch stations to those embodying duplicate busbars and the control gear for many feeders.

In the following table a list is given of the 132 kV sub-stations in the Central England area, showing the type of station installed and the number of oil circuit breakers employed.

Station.	Type.	No. of 3-phase oil circuit breakers.
Hams Hall	High Double Busbar	9
Ocker Hill	,, ,,	8
Nechells	,, ,,	6
Leicester	,, ,,	4
Ironbridge	,, ,,	2
Coventry	,, ,,	4
Nottingham	,, ,,	5
Spondon	,, ,,	4
Stourport	,, ,,	6
Wolverhampton	Low Double Busbars	6
Bartley Green	High Extensible	3
Burton	Low Non-Extensible	3
Loughborough	,, ,,	3
Northampton	,, ,,	3
Stafford	,, ,,	3
Stoke	,, ,,	3
Warwick	,, ,,	3
Worcester	,, ,,	3
Total number of 3-phase oil circuit breakers		78
Total number of 132 kV rotating isolating links		253

The whole of the Central England system is under the control of the C.E.B. authorities at Grid House, Wake Green Road, Birmingham, where a central indicating switchboard has been installed by the G.E.C. and affords a visual representation of the conditions at all stations in the area. The operator can thus see at a glance the transformer tapping positions, the total load being handled, the wattless kVA in each section of the system and a mimic diagram of the main connections at each sub-station, embodying coloured lamps which indicate whether the associated circuit breakers are open or closed.

The switchboard comprises 21 polished slate panels arranged in the form of a horse-shoe (fig. 5).

Remote indications for the various outdoor sub-stations are transmitted to this control board by a special supervisory control system developed by The General Electric Telephone Works at Coventry, a full description of which will appear in a future article in this series.

The operators are able to place themselves in direct telephonic communication with any of the sub-stations by means of telephone equipment working over the pilot wires used for the supervisory control system, and can thus issue any necessary instructions for the smooth working of the system as a whole.

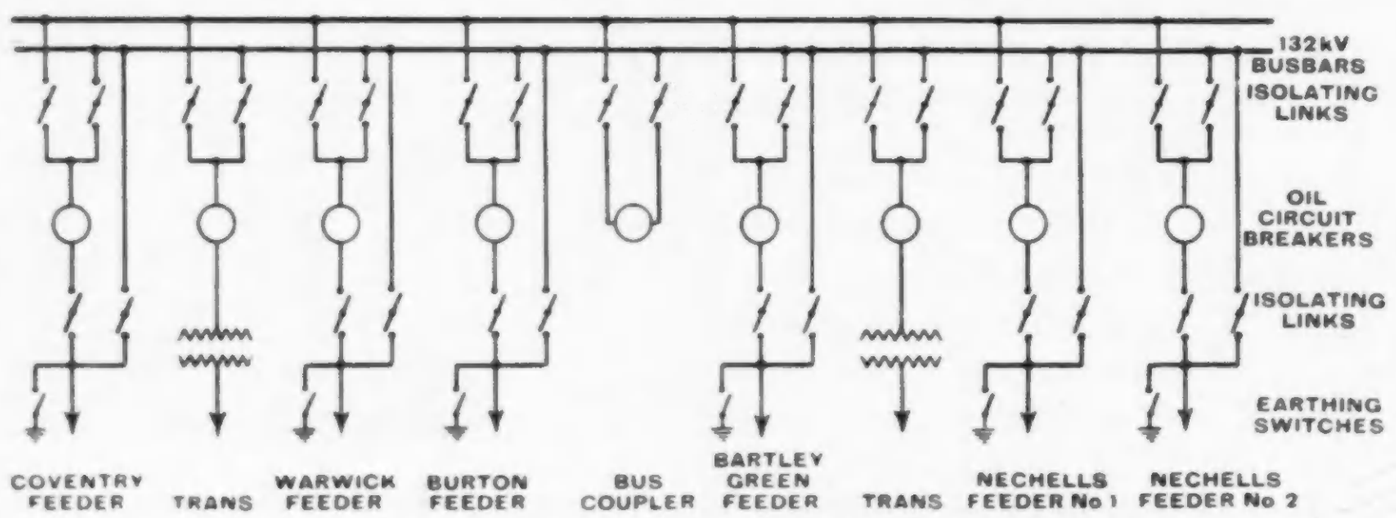
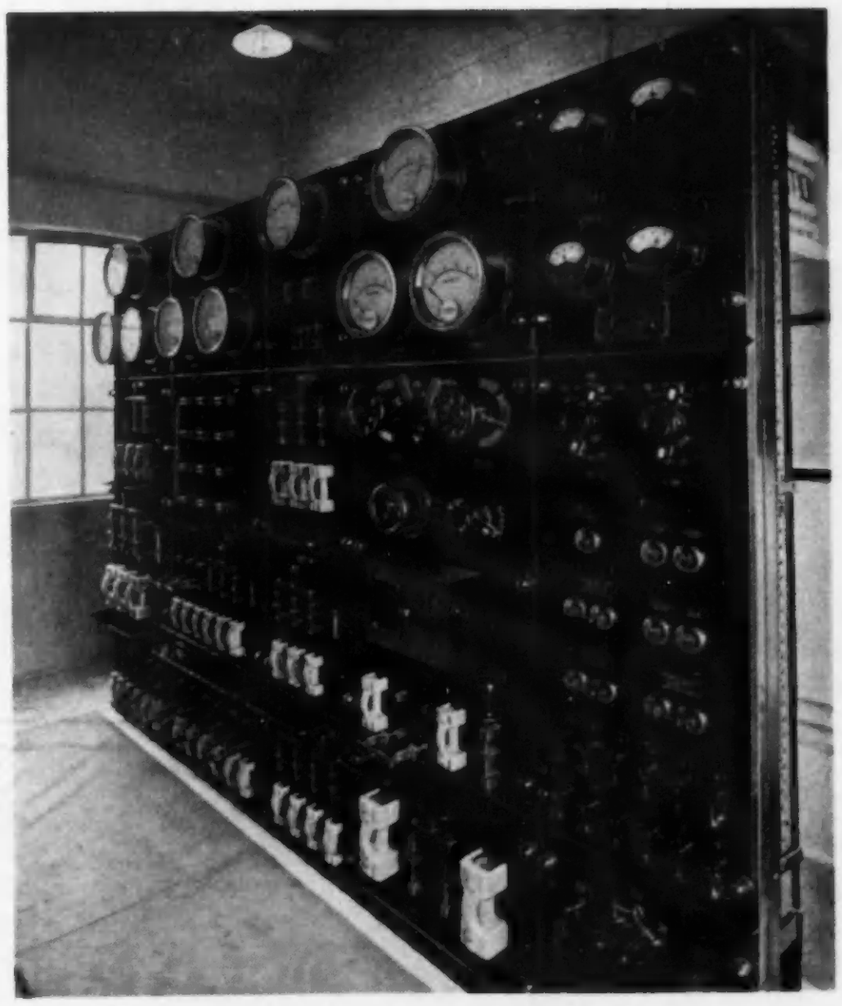


Fig. 7.—Diagram of connections at Hams Hall sub-station.

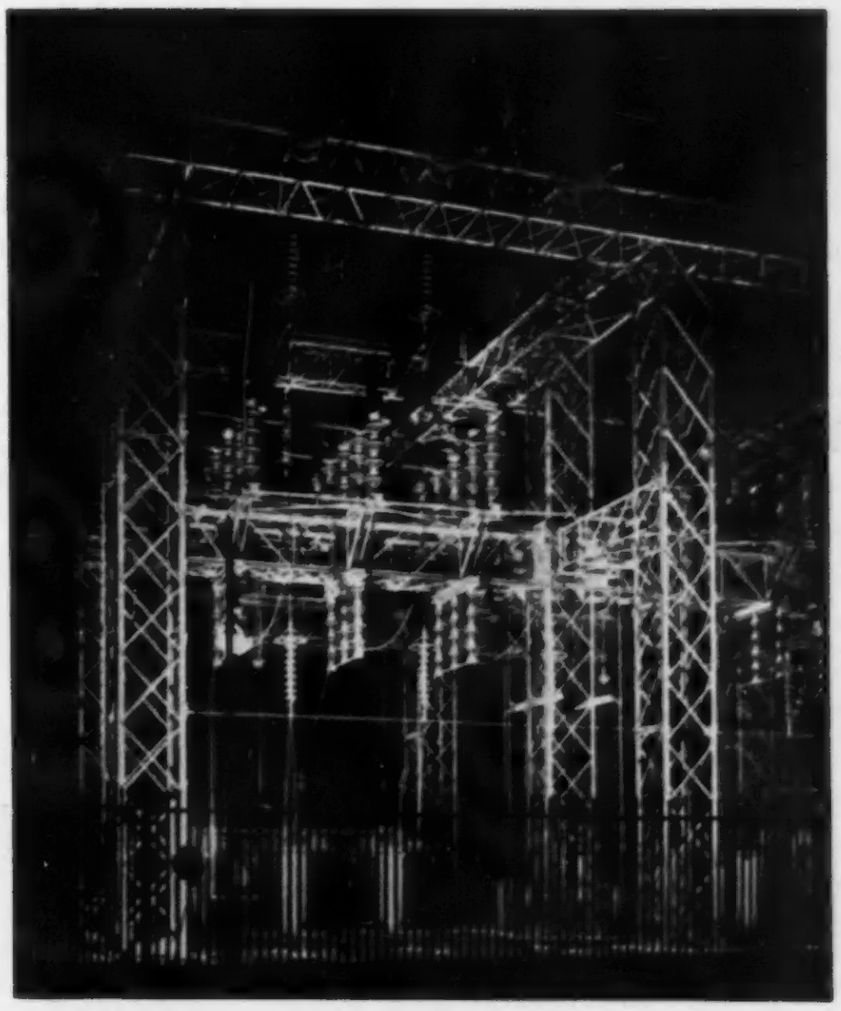
In figs. 1, 6, 11, 13 and 15 are shown views of the four different types of sub-station at Hams Hall, Wolverhampton, Bartley Green and Burton. As these sub-stations are representative of the scheme as a whole, it is proposed briefly to describe each in the order given.

G 4079

Fig. 8.—Remote control switchboard at Hams Hall Generating Station, controlling the outdoor sub-station.



G 4082



G 4085

Fig. 9.—A.C. and D.C. switchboards in the auxiliary plant house at Hams Hall sub-station.

Fig. 10.—View by night of floodlighting of part of Hams Hall outdoor sub-station.

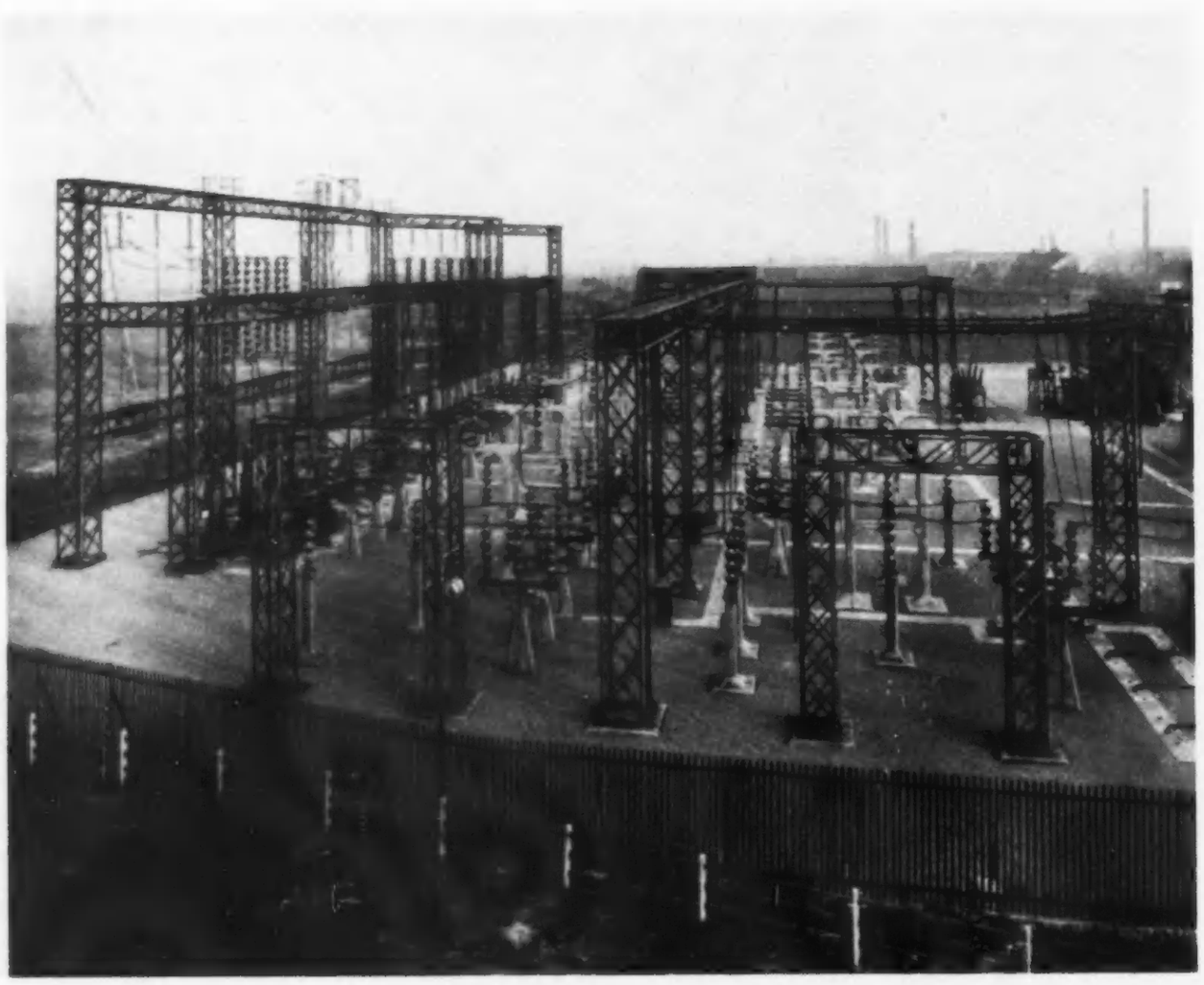
HAMS HALL OUTDOOR SUB-STATION.

Situated close to the Hams Hall Generating Station, the Hams Hall outdoor sub-station is the largest in the Central England area, having six feeder circuits, a bus coupler and two transformer circuits (see diagram fig. 7). The six feeders interconnect with sub-stations at Coventry, Warwick, Burton, Bartley Green and two with Nechells. The station is of the H.D.B. type and is divided into nine bays, one for each of the nine circuits controlled. The six feeder bays are each equipped with a 132 kV 3-phase oil circuit breaker and four 132 kV 3-phase rotary type isolating links, while the transformer bays are provided with a 132 kV 3-phase oil circuit breaker and two 132 kV 3-phase rotary isolating links. The bus coupler bay has a 132 kV 3-phase oil circuit breaker connecting the two busbars together, and two 132 kV 3-phase rotary isolating links, one on each side of the breaker.

The oil circuit breakers are located on the ground while the rotary links are bolted to the structural steelwork and are manually operated at ground level through a system of levers. Connections from the high tension side of each of the two transformers are taken up to auxiliary busbars suspended from string insulators mounted on a low extension of the main structural steelwork. From these busbars the supply is led to the terminals of a 3-phase oil circuit breaker, the other terminals being connected to the fixed post insulators of two rotary links. These enable the supply to be connected to either of

the two sets of busbars which run along the top of the steel structure and are supported by post type insulators.

In the case of feeder circuits, each set of busbars is connected to the oil circuit breakers through



(*By courtesy of Messrs. Highfield and Roger Smith*).

Fig. 11.—General view of the low double busbar sub-station at Wolverhampton.

separate rotary isolating links, a further isolating link being inserted between each breaker and outgoing feeder.

In order to guard against faulty operation of the rotary isolating links, Castell figure locks are provided which, as previously explained, prevent an isolator being opened or closed unless its associated breaker is in the open position.

Control Room.—The oil circuit breakers are remote controlled from a switchboard (fig. 8), installed in the main control room in Hams Hall Generating Station. The control board embodies a mimic diagram of the 132 kV connections, automatic indicators of isolator and oil circuit breaker positions being given on electromagnetic semaphores which are operated from auxiliary contacts on the outdoor switches. Synchronising gear, ammeters and voltmeters and inter-tripping relays (working in conjunction with the protective equipment) form part of the control board. Control gear of the transformer on-load tap changing equipment is mounted on one of the panels of the main control board.

On the wall at the end of the control room is drawn a large diagrammatic representation of the Central England Scheme, enabling the operator to have a clear representation of the interconnections always before him.

Metering equipment is also installed in the control room. This will be described in a subsequent article dealing with this subject.

Auxiliary Plant House. — A separate building, erected within the area of the outdoor sub-station, houses the auxiliary plant, comprising auxiliary A.C. and D.C. switchboards, 110 volt battery and battery charging equipment, protective relay panels and supervisory control gear cubicles, and oil filtering plant. This equipment is contained in three main rooms, the battery room, the electrical plant room and the oil filtering room.

The battery provides a D.C. supply for the closing and opening of the circuit breakers and also a small supply for emergency lighting. A small motor generator set is installed for charging the batteries when necessary, while a metal rectifier provides continuous trickle charging.

In the electrical plant room the D.C. switchboard, fig. 9, controls the circuits supplying the operating coils of the oil circuit breakers and other auxiliary D.C. equipment in the station. The A.C. board is lined up with the D.C. board, both being of the

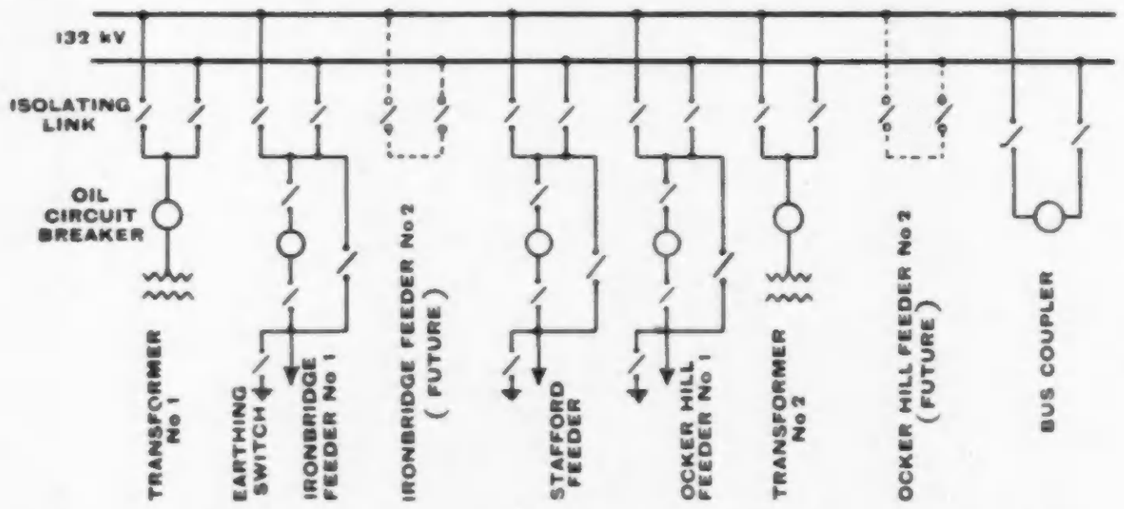


Fig. 12.—Diagram of connections at Wolverhampton sub-station.

flatback type, and controls the incoming supply from two auxiliary transformers which are connected on their H.T. side direct to the L.T. side of the main power transformers. The voltage of the secondary side of the auxiliary transformers is 400. The A.C. circuits controlled comprise those of the pumps and fan motors for the power transformers, tap changing gear, station lighting and oil filtering plant.

The relays are mounted on a slate panel of flat-back construction housing all the protective relays associated with the 132 kV gear.

Supervisory indicating equipment is also contained in sheet steel cubicles in the electrical plant room.

Lighting.—The lighting of the station is carried out by electric lanterns and floodlights (fig. 10). "Wembley" lanterns containing 500 watt Osram lamps are suspended from the steelwork, while 1000 watt floodlight projectors mounted on 25 ft. poles are provided at each corner of the station and at other strategic points. Two further 1000 watt floodlights of the portable type fitted with narrow and wide angle reflectors enable any particular portion of the structure to be illuminated. For this purpose 230 volt plug points are fixed at points on the structure giving an A.C. supply either for lighting or for the driving of electric tools.

WOLVERHAMPTON SUB-STATION.

While the sub-station at Wolverhampton, fig. 11, presents a very different appearance from that of Hams Hall, the electrical arrangement is similar in practically all respects. In place of the H.D.B. type of structure, the L.D.B. form has been adopted in which most of the equipment is located either on the ground, as in the case of the oil circuit breakers, or on reinforced concrete pedestals, as in the case of the rotary isolating links. It will be seen from the diagram, fig. 12, that connection to either set of duplicate busbars is effected through rotary isolating links. The latter are arranged in four rows running almost the entire length of the station with the busbars running parallel between and above each pair of rows. The busbars are supported on post type insulators mounted on reinforced concrete pedestals.

In the case of feeders, connections are taken from these isolating links, through a further isolating link, to the oil circuit breaker. Thence they are led up to a superstructure to an isolating link, the other side of which is connected to the outgoing line. Provision is made for earthing the outgoing feeder and for by-passing the oil circuit breaker during maintenance work.

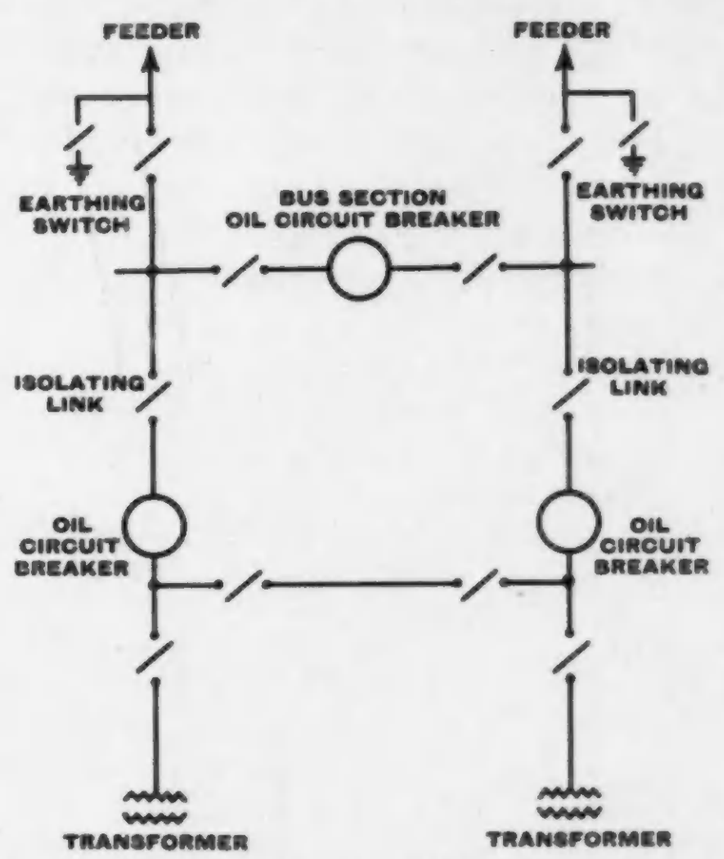
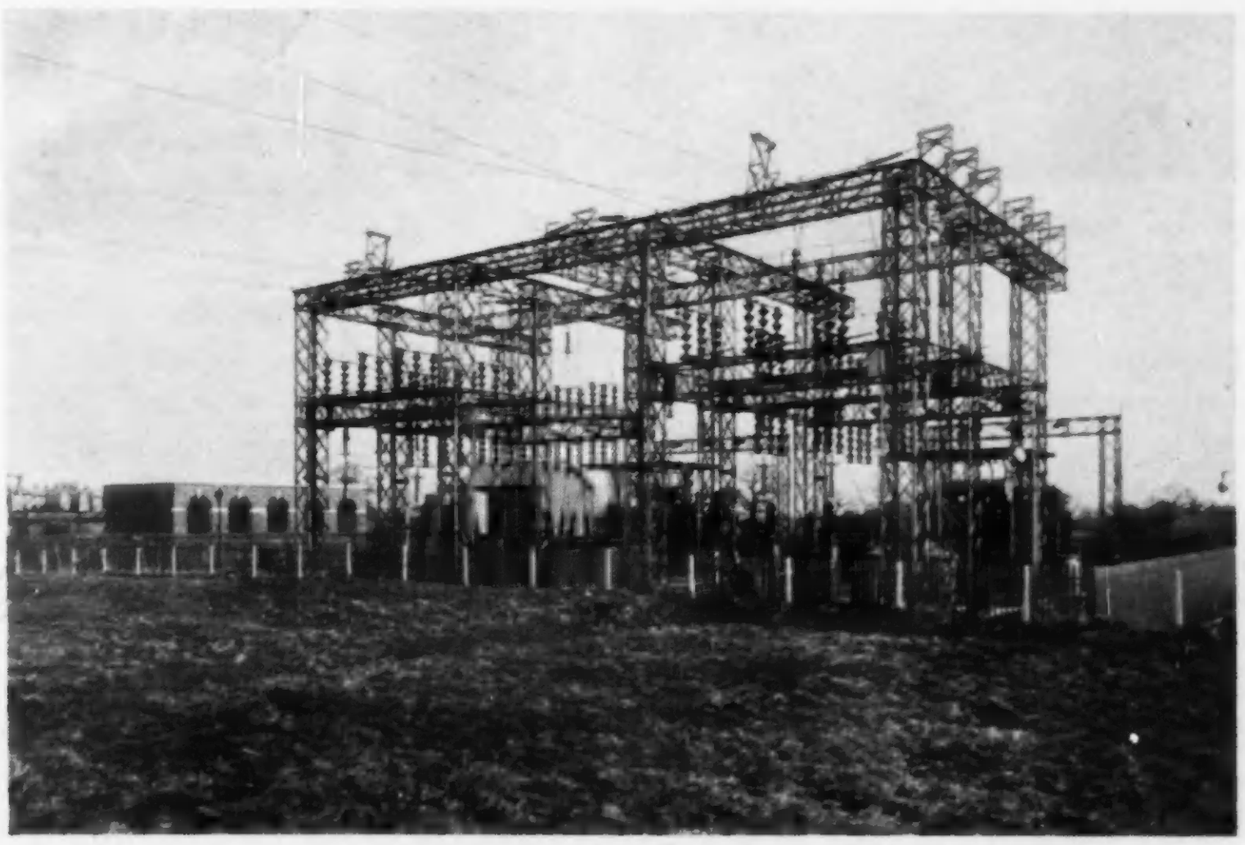


Fig. 14.—Diagram of a typical 3-switch station.



G4137

Fig. 13.—Bartley Green sub-station, typical of the high extensible type of structure.

The feeders interconnect with stations at Ironbridge, Stafford and Ocker Hill, while facilities for two future duplicate feeders to Ironbridge and Ocker Hill are available.

The remainder of the equipment, including the control board, auxiliary plant house, lighting of the station, etc., is similar to that at Hams Hall.

BARTLEY GREEN SUB-STATION.

A typical H.E. type of station is that at Bartley Green, fig. 13, where a section connected arrangement has been adopted. The diagram, fig. 14, shows that three oil circuit breakers are installed.

The three-circuit breaker type of sub-station is used in considerable numbers on the British Grid. It contains two transformers for converting the 132 kV power to the local voltage and is connected in a 132 kV ring main—that is to say, there are two 132 kV three-phase lines connected to it, one in and one out, although the electric power may flow in either direction of the lines. Hitherto, for

such a station four 132 kV circuit breakers would have been considered necessary, namely, one for each transformer and one for each line. The three-switch station enables a saving of 25 per cent in this connection to be made and at the same time provides adequate control and protection. It is, of course, not claimed that the three-circuit-breaker station is as efficient as the four-circuit-breaker station, but as all engineering must be judged from its financial aspect, the scheme, taking everything into consideration, is justified.

By a system of interconnected current transformers which operate the protective relays, the following results are obtained. In the event of a transformer developing a fault it is disconnected from the 132 kV system by its own circuit-breaker, while at the same time it is also disconnected from the local system by the operation of its lower voltage circuit breaker; should one of the 132 kV transmission lines prove faulty it is disconnected by the simultaneous opening of the section circuit breaker and the 132 kV circuit breaker on the transformer adjacent to the line which is at fault.

As in the case of the H.D.B. stations, the rotary isolating links at Bartley Green are all mounted on the structural steelwork which can be extended at any future date to form an H.D.B. station.

The two feeders can be seen in fig. 13, attached to string insulators at the top of the structure and the two earth wires attached to the two small towers at the top and at the centres of the two outer bays. The feeders interconnect with Hams Hall and Stourport. Behind the station in the centre may be seen the auxiliary plant house at the side of which are the clean and dirty oil tanks, while on the left is a sub-station of Birmingham Corporation's Electricity Dept., in which is installed an 11,000 volt G.E.C. metalclad switchboard connected to the main power transformers.

BURTON SUB-STATION.

The L.N.E. station at Burton is a further example of the 3 switch station. In this instance, however, the low type of construction is employed and is clearly illustrated in fig. 15. In the right foreground are the two feeders to Spondon and Hams Hall supported on a double line tower.

Fig. 15.—The low non-extensible sub-station at Burton.

As regards maintenance, cleaning and adjustment of all apparatus on these 3 switch stations, examination of the diagram in fig. 14 with special reference to the by-pass isolating links shows that these important points are fully cared for. Under ordinary running conditions the isolators in the by-pass are, of course, open.

SUPERVISORY CONTROL AT LOUGHBOROUGH.

Before leaving the Central England Scheme it should be mentioned that the sub-station at Loughborough is situated about 1¼ miles from the power station from where it is operated by remote supervisory control. No control board is therefore installed at the outdoor station, all necessary indications of oil circuit breaker positions, transformer tappings, etc., being transmitted back to the power

station by supervisory means. This will be dealt with fully in a future article.

SOUTH-WEST ENGLAND SCHEME.

In the South-Western area, a map of which is given in fig. 16, the G.E.C. were entrusted with the manufacture and erection of twelve 132 kV outdoor stations at Oxford, Plymouth, Nursling, Bourne Valley, Dorchester, Exeter, Bridgewater, Newton Abbot, Portsmouth, Fraddon, Hayle and Southampton. Messrs. Kennedy & Donkin were the consulting engineers for this scheme. In all cases but Southampton, the low type of station with reinforced concrete structures (similar to the L.N.E. type in the Central England Scheme) has been adopted.

The following table gives the location of the eleven stations, their type and the number of single-phase oil circuit breakers installed. As regards the type number, the first of the five symbols gives the number of feeders; the second indicates the method of coupling (in all these instances a section coupled station is employed); the third gives the number of transformers; while the fourth and fifth respectively signify the subsidiary connection (X = crossover, M = mesh) and the number of 3-phase oil circuit breakers. Thus a station of type 2S2X3 has two feeders, is section connected, has two transformers and three 3-phase oil circuit breakers and the subsidiary connections are of the crossover arrangement.

Station.	Type.	No. of 3-phase Oil Circuit Breakers.
Oxford	2S2X3	3
Newton Abbot	2S2X1	1
Plymouth	2S2X3	3
Bourne Valley	2S2X3	3
Nursling	4S2M6	6
Portsmouth	2S2M3	3
Bridgewater	2S2M3	3
Exeter	3S2M5	5
Dorchester	2S2X1	1
Fraddon	2S2X1	1
Hayle	1S2X1	1
Southampton	Special	—

The station at Southampton is a small terminal station of special type. Two feeders from Nursling are connected to two 132 kV transformers each through a rotary type isolating link. As the station does not form part of the ring main system of the Grid, it has not been necessary to instal oil circuit breakers for controlling the transformers or lines, any such control being effected from Nursling.

The three stations at Oxford, Plymouth and Bourne Valley are all of the 3-switch arrangement previously described, a diagram of which is given in fig. 14. At Newton Abbot, Dorchester, Fraddon and Hayle, a single circuit breaker arrangement, fig. 17, has been adopted which has certain features of interest.

Protection of the 132 kV lines is secured by interlocking the 132 kV circuit breaker with the lower voltage transformer circuit breakers; should a

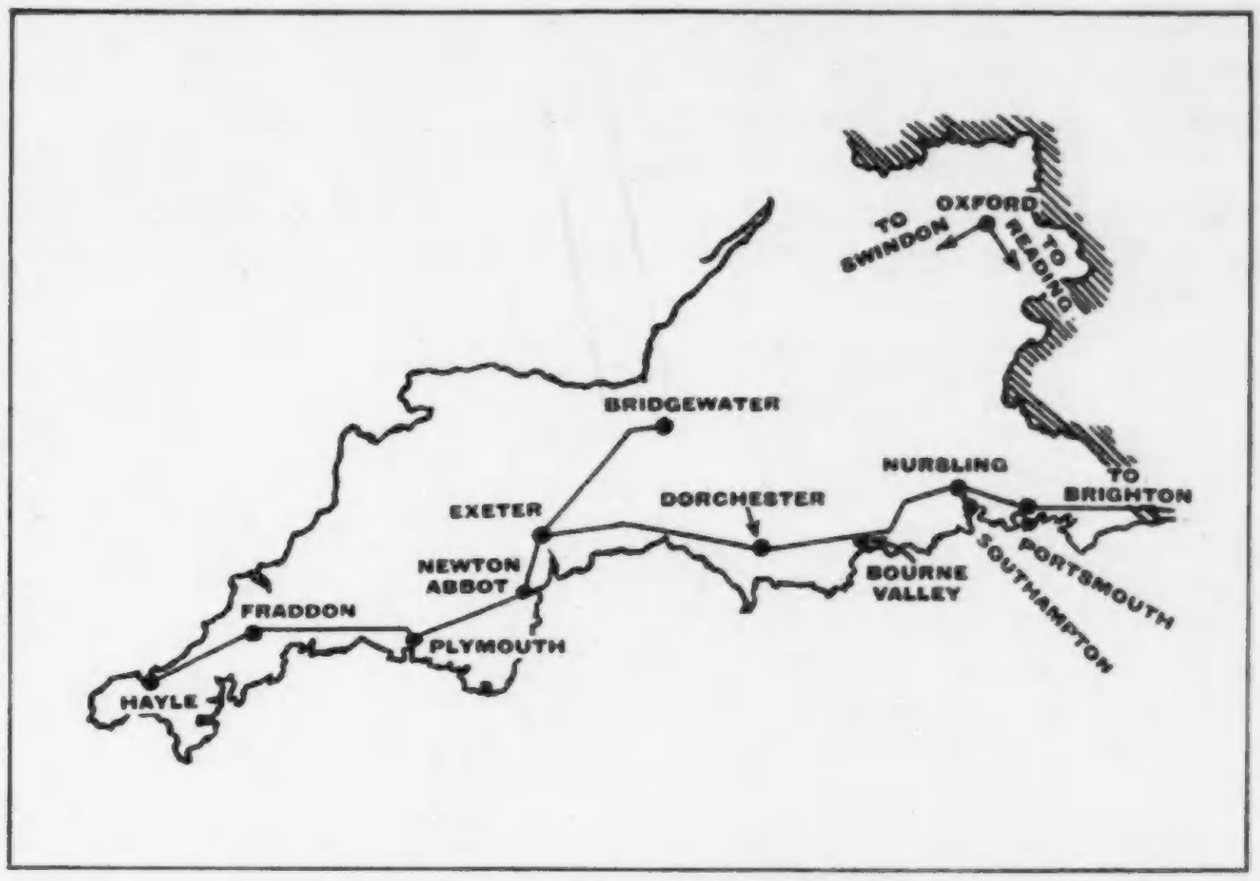


Fig. 16.—Map of the South-West England area.

fault develop on one of the lines, the 132 kV circuit breaker and the lower voltage transformer breaker, which is on the transformer adjacent to the faulty

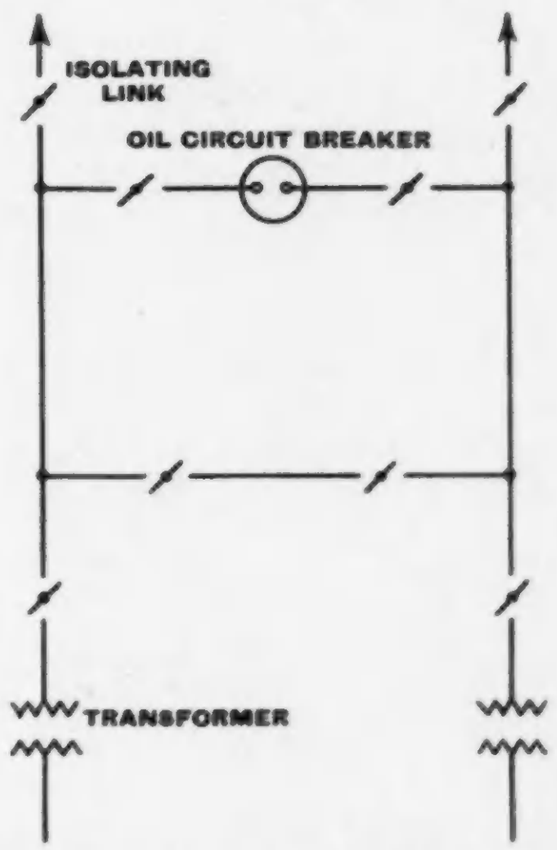


Fig. 17.—Diagram of a typical single switch station.

line, are opened. A fault on a transformer likewise opens its lower voltage circuit breaker and the 132 kV oil circuit breaker, but as the faulty transformer still remains connected to its adjacent line, a special form of protection comes into action which cuts off the line at the next sub-station. Naturally,

the single-circuit-breaker station is less convenient than the three-circuit-breaker type, inasmuch as the disconnection of a faulty transformer involves the switching out of a section of the line. A transformer fault is, however, nowadays a rare occurrence, and consequently for the less important districts the use of the single-breaker type is fully justified.

Another feature of this type of sub-station is that the isolating links on the 132 kV side of the transformers must be capable of breaking the magnetizing currents of the transformers. This condition is satisfied by the addition of arcing horns to the standard form of isolator, as the arc due to the rupture of the 132 kV magnetizing current is only a few inches long.

As regards the mesh connected type of station, that at Nursling is representative and a diagram of connections is given in fig. 18. In the following description of Nursling station those sections dealing with the control boards, station auxiliaries and lighting may be taken as typical of all G.E.C. stations on the S.W. England Scheme.

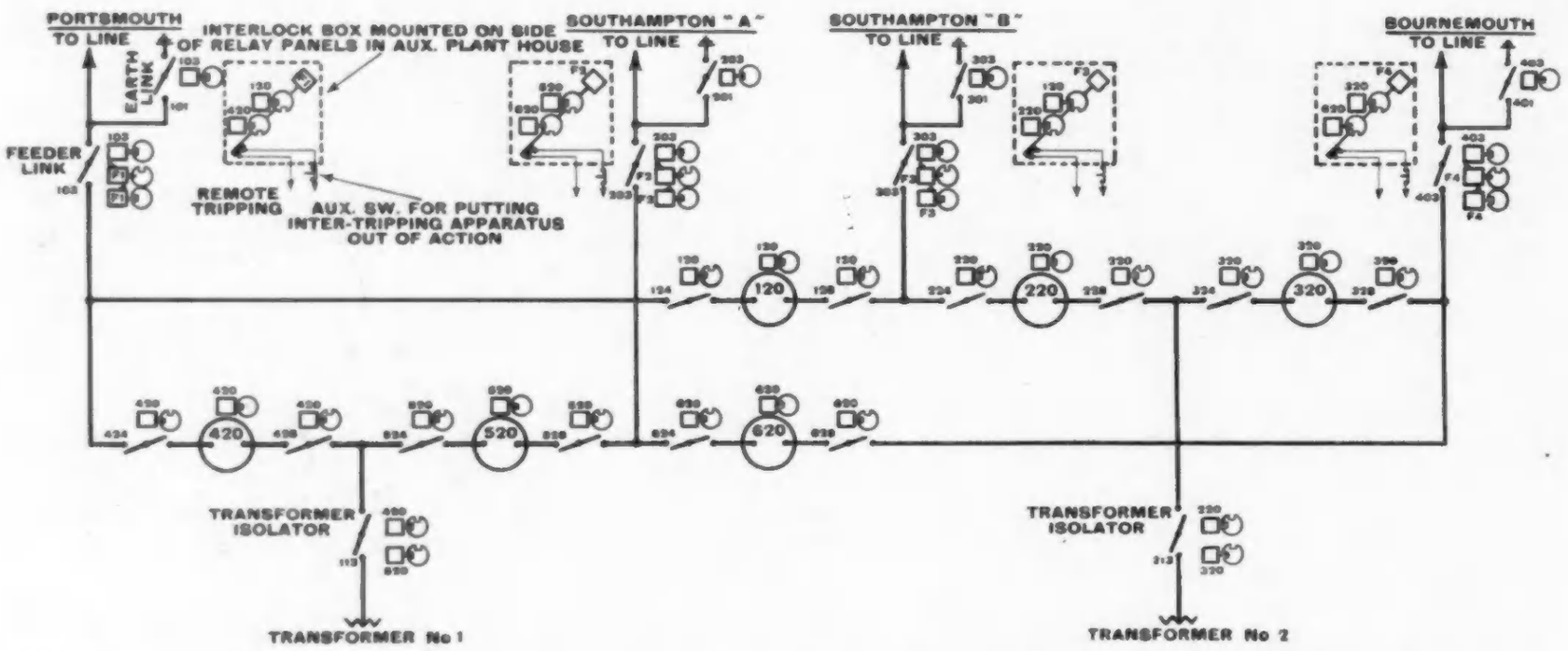


Fig. 18.—Diagram of connections at Nursling sub-station, showing the Castell method of interlocking.

NURSLING SUB-STATION.

The Nursling Outdoor sub-station (figs. 19 and 20) is situated north of Southampton and is the junction point of four 132 kV feeders connected to Portsmouth, Bournemouth and two to Southampton. The circuits controlled thus consist of these four feeders and two 132/33 kV 10,000 kVA 3-phase transformers.

The "low" type of construction is such that the isolators and overhead conductors, which are mounted on reinforced concrete trestles have a maximum height of about 30 feet.

The station is of the mesh connected type, the main station connections being arranged in the form of a ring from which the feeders and transformer circuits are teed-off. Each tee-off circuit, whether feeder or transformer, is separated from the adjacent circuit by one oil circuit breaker and two isolators, one isolator only being connected in the tee-off circuit itself.

The oil circuit breakers are remote controlled from a control board (fig. 21) installed in the Control Room adjacent to the station. The control board embodies a mimic diagram of the 132 kV connections, automatic indications of isolator and oil breaker positions being given on illuminated semaphores which are operated from auxiliary switches on the outdoor apparatus. The control gear for the oil circuit breakers and on-load tap changing gear is also mounted on this control board.

Paper insulated trunk multi-core cables connect the control board and the outdoor switchgear and terminate at the outdoor site in a junction box (fig. 22). Within the trunk junction box the cores are interconnected with cores of smaller cables, which, in turn, are connected to the various isolators and oil breakers of the particular section with which they are associated.

The Auxiliary Plant House is divided into three main rooms—the Battery Room, the Electrical Plant Room, and the Oil Filtering Room. The Battery Room contains a 110 volt battery which provides a D.C. supply for the closing and opening of the circuit breakers and also a small supply for emergency lighting. The Electrical Plant Room contains a D.C. switchboard, a low tension A.C. switchboard, relay board and supervisory cabinet. The Oil Plant Room as the name implies, houses the necessary pumps and filters for purifying the large quantity of oil contained in the oil circuit breakers and power transformers.

In the Electrical Plant Room the D.C. switchboard controls the circuits supplying the operating coils of the oil circuit breakers and other auxiliary D.C. supplies on the station.

The low tension A.C. switchboard is of the ironclad type and comprises two oil circuit breakers

which control the incoming supply from two auxiliary transformers. These auxiliary transformers are connected on their higher voltage side direct to the low voltage side of the main transformers. The voltage of the secondary side of the auxiliary transformers is 400.

The relay board is a steel fronted board of cubicle construction and houses all the protective relays associated with the 132 kV gear. Special testing switches are incorporated in this board to enable the various current transformers to be short circuited and a portable testing set to be plugged direct on to the relay terminals in order that periodical testing of the relays may be carried out.

LIGHTING.

The general lighting of the outdoor station is carried out by means of floodlights. The four main units, each consisting of a 1000 watt projector, are mounted in pairs on concrete poles 30 feet high, one pole being situated at each of the two corners of the station nearest to the power transformers.

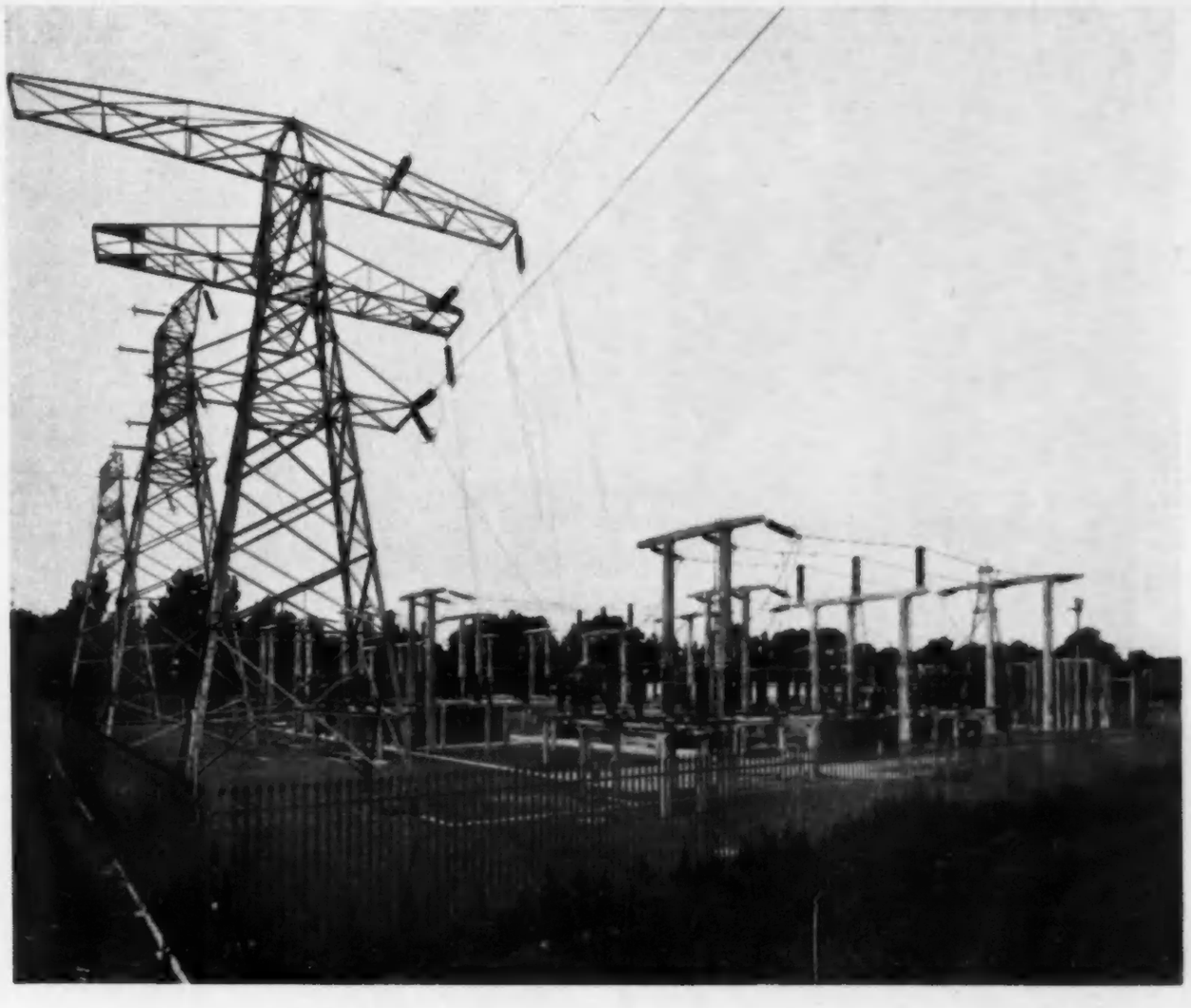
Two pairs of rectangular reflectors, each containing a 500 watt lamp, are fixed to the terminal towers supporting the incoming 132 kV lines.

In addition to the lighting units, watertight plugs and sockets are mounted at convenient points on the concrete structures, and portable floodlights are provided for plugging into the sockets so that a concentration of light can be obtained for maintenance work at night time.

MID EAST ENGLAND SCHEME.

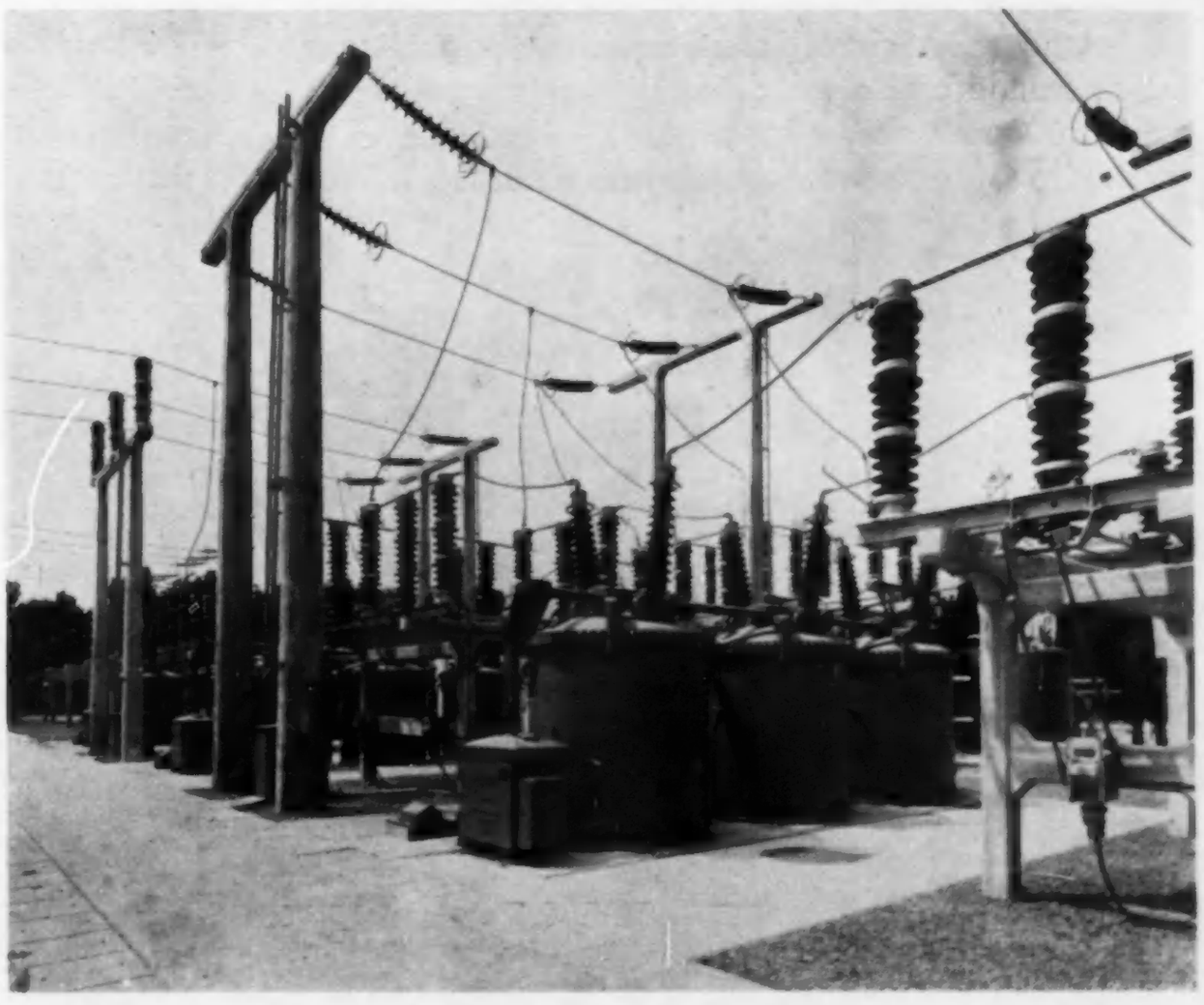
For the Mid East England area the G.E.C. supplied six 132 kV 30,000 kVA transformers fitted with on-load tap changing gear. These were designed to the specification of Messrs. Merz & McLellan, consulting engineers. The transformers are installed two at each of the outdoor stations at Kirkstall, Rotherham and Bradford. The two units at Kirkstall are designed for a ratio of 132/11 kV and the other four for a ratio of 132/66 kV at 50 cycles per second.

All six units are capable of dealing with a load up to 15,000 kVA under natural radiating conditions, for which purpose special radiators are fitted. For the 30,000 kVA load a forced air blast is directed on to the radiators by suitable motor-driven fans from air ducts built round the bases of the transformers. These motors are automatically started by thermostat control. A view of one of the transformers on site is given in fig. 23.



G4204

Fig. 19.—General view of Nursling sub-station in the South West England area.

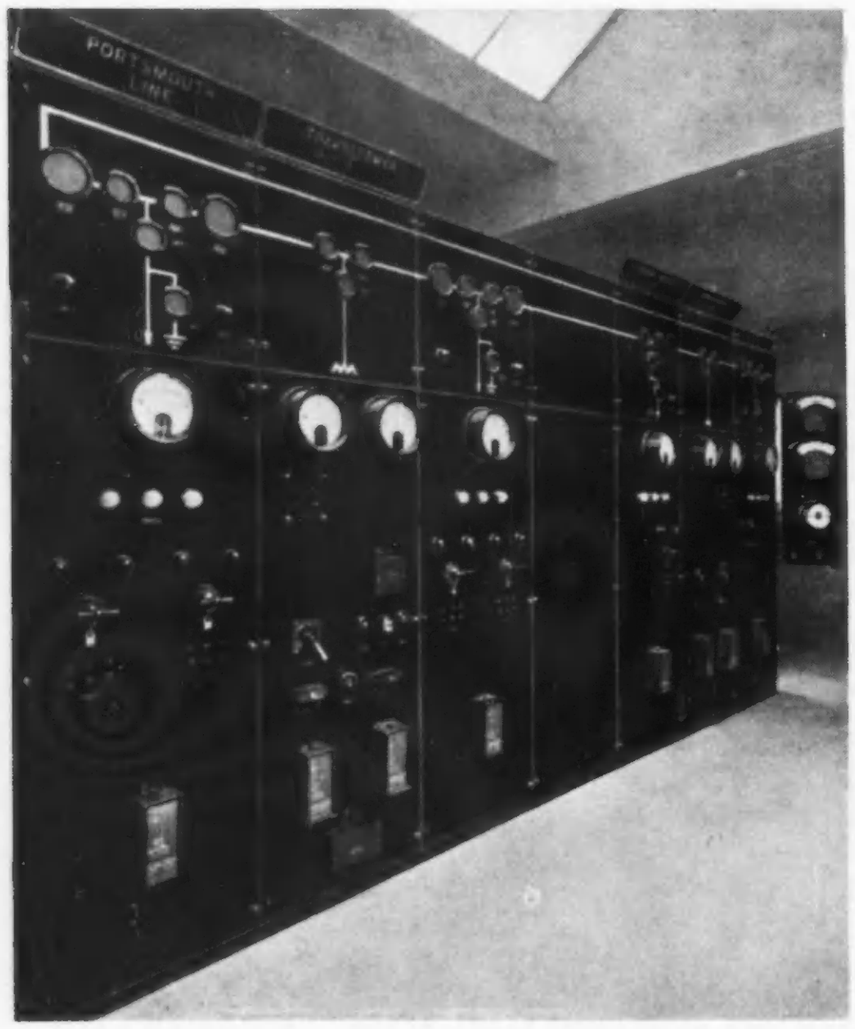


G4203

Fig. 20.—Another view of Nursling sub-station showing the 132 kV oil circuit breakers.

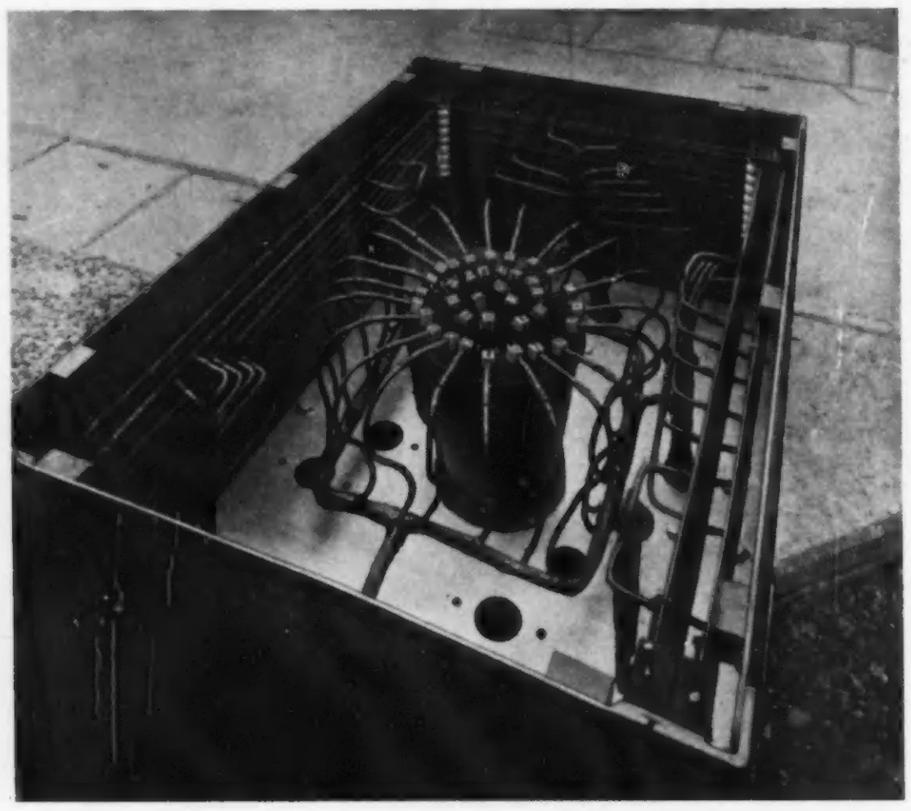
Features of the design of these transformers include the provision of special static end rings fitted on the H.T. winding affording protection against surges, and the bracing of all windings to withstand short circuit conditions. A special type of automatic coil clamp is fitted which enables the coils to move in a longitudinal direction when expanding due to heat. Paper insulation is used for insulating the copper strips and strand used in the construction of the windings. Between the windings and the core, treated cardboard is employed as an insulator.

Condenser type terminal bushings fitted with current transformers are used on the H.T. side, with the usual porcelain terminals on the L.T. side.



G 4206

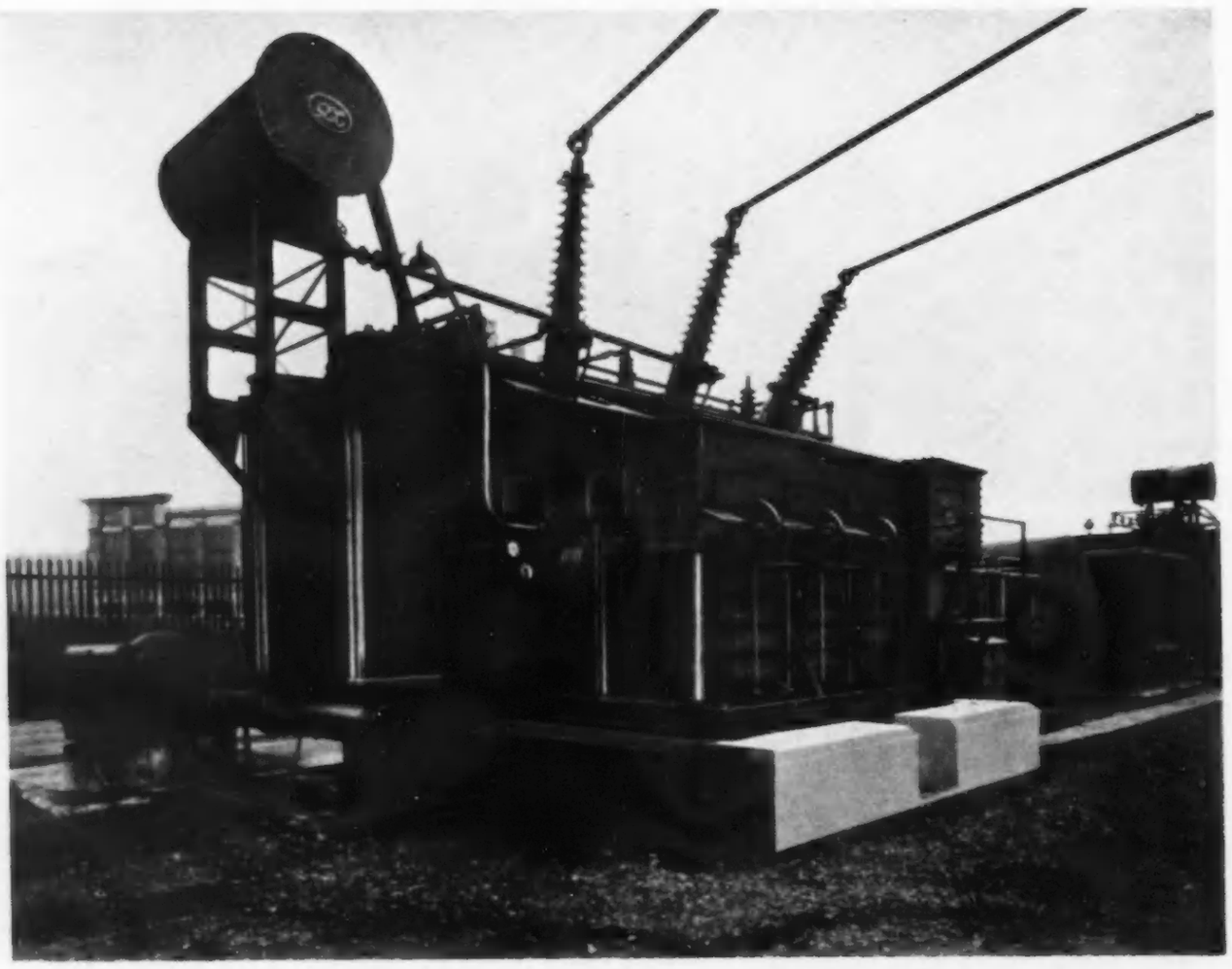
Fig. 21.—Remote electrical control board installed in Control Room at Nursling sub-station.



G 4205

Fig. 22.—Outdoor junction box interconnecting control board with outdoor switchgear.

Alarms are installed to indicate excessive temperature of either the oil or the windings, in which case protective gear will operate to trip the transformer circuit breakers.



G 3831

Fig. 23.—One of the 132 kV, 30,000 kVA transformers with on-load tap-changing gear, installed in the Mid East England area.

The on-load ratio control gear, which is fitted for tap changing under load, gives a variation of the effective transformation ratio from 10 per cent below normal to 10 per cent above normal in steps of 1.43 per cent of the normal ratio. The gear is arranged for remote electrical operation from a control board on which are mounted remote ratio indicators.

A full description of the type "G" on-load tap changing gear used on the grid transformers appeared in the *G.E.C. Journal* (Vol II, No. 3—"Load Ratio Control for Transformers").

NORTH WEST ENGLAND SCHEME.

So far only 132 kV equipment for the grid has been dealt with. There is, however, a considerable amount of gear which the G.E.C. has installed in connection with the lower voltage secondary lines. A notable example is the North West England area (for which Messrs. Kennedy & Donkin were consulting engineers), where seven G.E.C. 33 kV stations are installed at Whitehaven, Glossop, Penrith, Stainburn, Chester, Alderley Edge, and Accrington. These stations are equipped with either one or three oil circuit breakers, etc., as set out in the following table.

Station.	Type.	No. of Three-phase Oil Circuit Breakers.
Whitehaven	D1	1 (hand operated)
Glossop	D1	1 ,, ,,
Penrith	D1	1 ,, ,,
Stainburn	D1	1 ,, ,,
Chester	D3	3 (elec. operated)
Alderley Edge	S1	1 ,, ,,
Accrington	D3	3 ,, ,,

The oil circuit breakers installed at all the stations are of a smaller type than those used on the 132 kV lines, and have a breaking capacity of 750,000

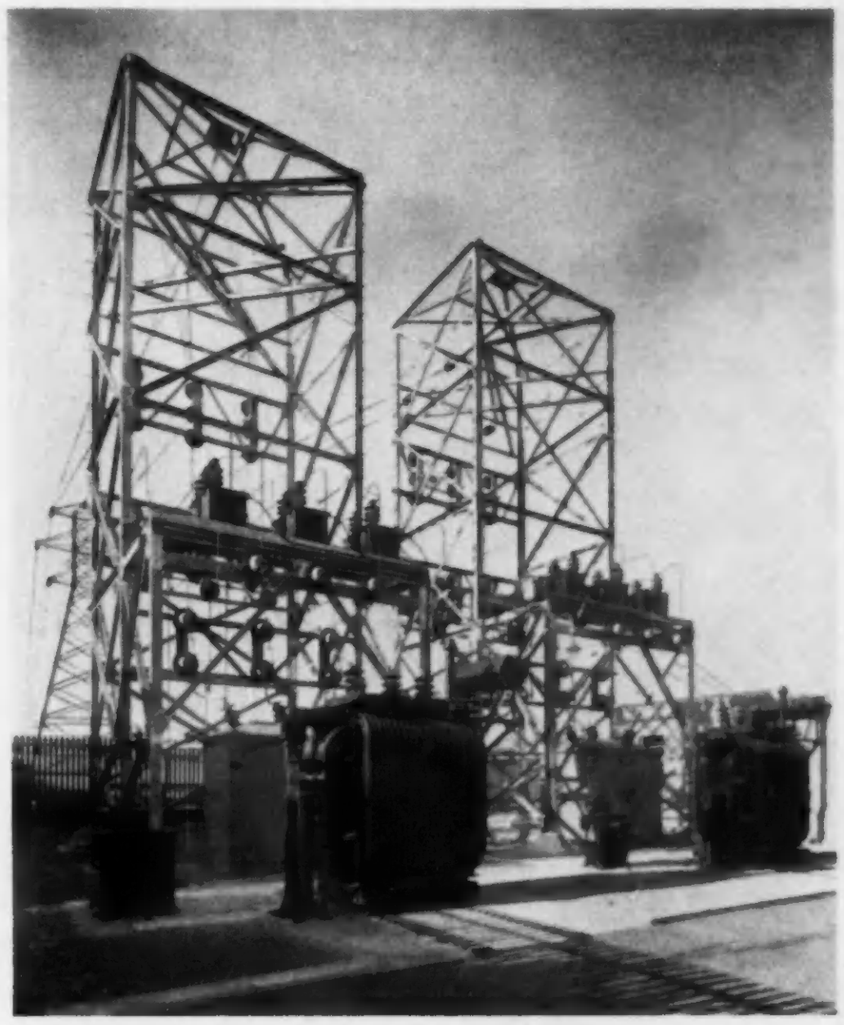


Fig. 25.—33 kV single switch sub-station at Penrith.

kVA. As in the case of the 132 kV breaker, a separate switch body and tank is provided for each phase, but the tanks and switches are mounted on a steel

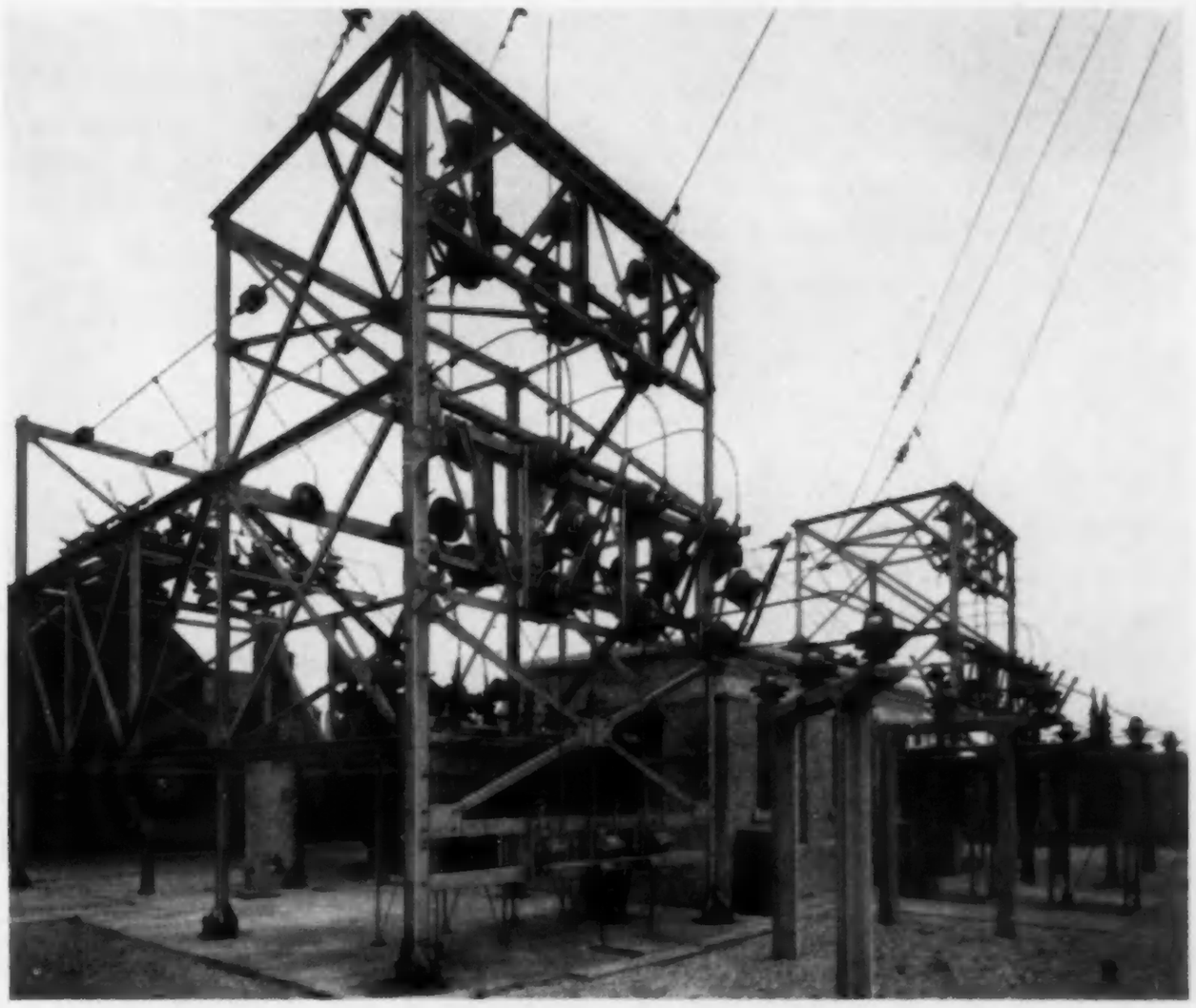


Fig. 24.—A typical 33 kV 3-switch sub-station in the North West England area; view of Chester station.

framework of sufficient height to allow the tanks to be lowered for inspection of the switches. The breaker is "free handle" throughout its full travel and is released by a relay operated trip coil, the relays being energised from bushing type current transformers mounted under the breaker top housing. In the electrically operated type a solenoid closes the breakers through a linkwork system which imparts a true vertical movement to the contacts.

CHESTER 33 kV STATION.

A view of the Chester station is given in fig. 24. It will be seen that all the isolating links, of which

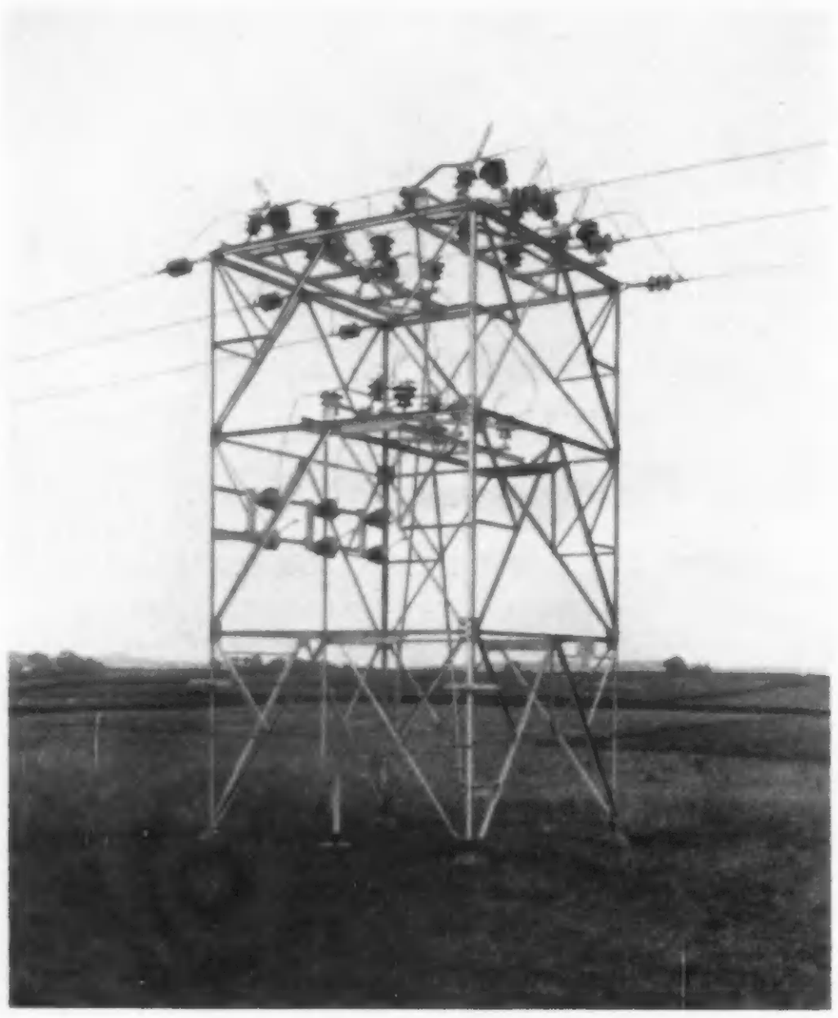


Fig. 26.—One of the 33 kV tapping points in the South Scotland area.

there are ten 3-phase units, are mounted in two parallel rectangular steel structures each 27 ft. high.

These links are of the gang operated type in which three insulators posts are provided per phase, the isolating link pivoting on one of the outer posts, being operated by the "push-pull" movement of the middle post and making contact with the other outer post.

Where the isolating links are used to break the magnetising current of a transformer, steel arcing horns are fitted which prevent burning of the contacts by deflecting the arc stream in an outward direction.

The 33 kV overhead lines are brought direct to isolating links on each steel structure from which they are led down each through two sets of isolating links to the transformer oil circuit breakers. From here connections are taken through a further set of isolating links to the H.T. sides of two 7,500 kVA transformers. A section oil circuit breaker with isolating links on either side is connected between the two 33 kV feeders.

An auxiliary plant house is built between the two steel structures and houses the G.E.C. control board, protective gear, operating batteries, motor generator set, oil filtering equipment, etc. As in the case of the Central England and South West England Schemes the control board carries a mimic diagram affording a visual indication of the control of the switchgear, transformers, etc.

ACCRINGTON 33 kV STATION.

The electrical circuit arrangements at Accrington are precisely similar to those at Chester. As the station is some 1½ miles from Accrington power station, however, control of the station is effected in two ways—(1) either by local electrical control from a control board in the auxiliary plant house at the station, or (2) by supervisory control from the power station at Accrington. The method of supervisory control employed will be described in a subsequent article in this series.

SINGLE SWITCH 33 kV STATIONS.

The remaining five stations are all of the single switch type. A view of the station at Penrith is given in fig. 25, and is typical of the five stations. In each case the various isolating links are bolted to two steel towers and are operated manually at the base of each tower through a system of levers.

The 33 kV lines are led down through two isolating links on each tower to the transformers and are interconnected by a section oil circuit breaker and two isolating links. All the circuit breakers are hand operated with the exception of that at Alderley Edge where a control board is installed for electrical operation.

A simple system of lighting is carried out at all stations which varies with the particular conditions obtaining at each station.

SOUTH SCOTLAND SCHEME.

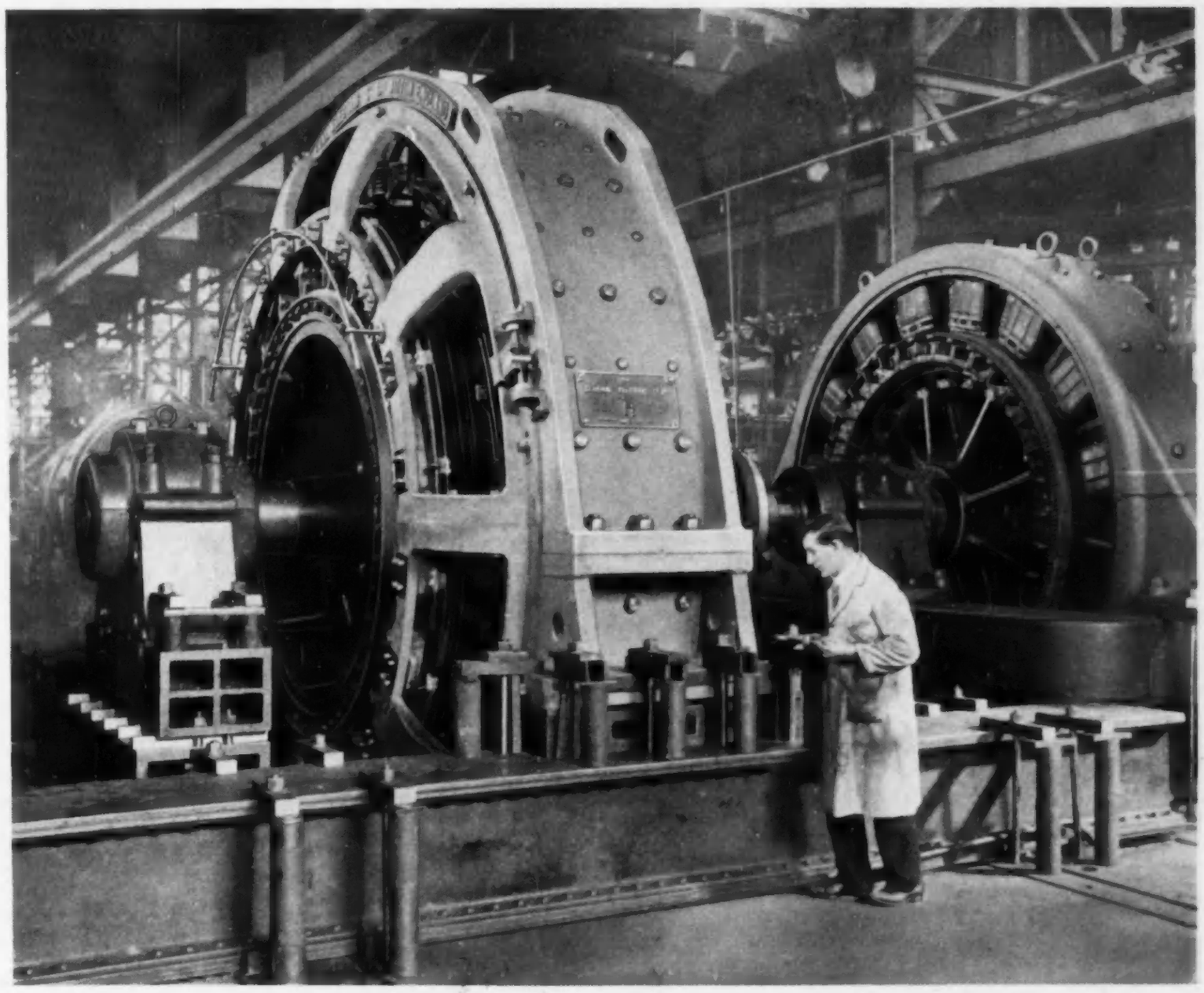
For the South Scotland Scheme a number of 33 kV tapping points have been installed in the section known as the "Berwick Ring." This section stretches from Berwick to Hawick, Hawick to Galashiels and Galashiels back to Berwick, involving a total length of overhead line of 95 miles.

This line obtains its power supply from the C.E.B. sub-station at Galashiels which taps off from the Dunston—Galashiels—Portobello 132 kV line. Tapping points are located at 12 points along the 33 kV line and consist of steel frames 14 ft. square

and approximately 28 ft. high carrying two line switches, one transformer switch and transformer fuses. Provision is made for mounting the transformers which were supplied under a separate contract. One of the switching stations is shown in fig. 25.

(*To be continued*).

Electric Winder for South Indian Gold Mines.



A 1200 h.p. 500 volt D.C. winder motor on test at Witton Engineering Works. It has been manufactured for the Champion Reef Gold Mine, South India and runs at a speed of 37.5 r.p.m.

G.4248

ADVERTISEMENTS.

A limited number of advertisements will be accepted for publication in the G.E.C. *Journal*.

Full information can be obtained on application to—

The General Electric Co., Ltd.,
Publicity Department,
Witton,
Birmingham.

G.E.C.

FRASER and CHALMERS

TURBO PLANT

Three G.E.C.-Fraser & Chalmers 3750 kW Turbo Alternators at the new Greaseproof Paper Mills of Messrs. Wiggins, Teape & Co. (1919) Ltd.

MADE IN ENGLAND.

The advantages that accrue from the use of G.E.C.-Fraser & Chalmers Passout Turbines in Paper Mills and other industries using steam for process purposes, are again emphasized by the choice of this plant for the new Greaseproof Paper Mills at Dartford of Messrs. Wiggins, Teape & Co. (1919) Ltd.

Each of these three sets has a capacity of 3,750 kW m.c.r. 3,300 volts, 3 phase 50 cycles, and is capable of passing out 45,000 lbs. of steam per hour at a pressure of 28 lbs. per sq. inch.